Possibilities of processing and marketing of products made from Antarctic krill

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PREPARATION OF THIS DOCUMENT

This document has been prepared as part of the FAO's Regular Programme activities concerned with the state and prospects of world fisheries. The study was designed to provide a realistic assessment of the prospects for the future development of the krill resources, based on recent technological developments and experiences. Through such studies, FAO seeks to anticipate developments that might affect the future demand and supply of fishery products. The authors of the paper worked in consultation with Dr. Z. Russek of the Sea Fishery Institute of Gdynia.

ABSTRACT

The potential development of krill has attracted attention for several years and has led to the publication of a large number of papers. Only a few of these, however, (most notably FAO reports prepared by Grantham in 1977 and McElroy in 1980) have dealt with all aspects of krill development in economic terms, from harvesting through processing to marketing. Since the preparation of the earlier FAO reports, research has introduced new elements concerning krill stock estimates and processing techniques. The progress made in processes and equipment for the production of peeled meat from krill is especially important since it indicates that products for human consumption, acceptable to the consumer, can be obtained. However, difficulties in solving economic and marketing problems still remain and it is these that, in the long run, will determine the viability of krill development.

The present study, based on the available literature and original analyses, takes into account the limitation resulting from the properties of the raw materials and presents the current state of possible commercial-scale uses of krill-processing technologies into products for human consumption, animal feed and industrial purposes. It also outlines views on marketing problems and provides examples of costs and prices of krill products already being produced or expected to be produced in the near future.

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1. INTRODUCTION

As a result of the search for new sources of animal protein of marine origin and the changes in the accessibility of fishing grounds in the 1970s, many states have shown increased interest in the possible utilization of Antarctic krill resources on a commercial scale. Some of them invested large amounts of money in research and commercial vessels in the Antarctic as well as in land-based laboratories, engaging specialists in many fields.

A great number of papers, usually dealing only with some aspects of this large subject, have been published. Only a few of them dealt with krill development as a whole; that is, with the technology of krill utilization, the mechanization of processing and the problems of economics and marketing. Most notable of these were the FAO reports prepared by Granthan in 1977 and McElroy in 1980, both of which provided summaries of the accomplishments made in this field.

In the period after the publication of the FAO reports, no new ideas in krill utilization were developed. However, research projects carried out by many countries have introduced new elements concerning krill stock estimates and processing techniques. The progress made during that period in processes and equipment for the production of peeled meat from krill is especially important since it indicates that products for human consumption, acceptable to the consumer, can be obtained.

However, difficulties in solving problems of krill processing and marketing still remain and it is they that, in the long run, will determine the economic viability of krill development.

The present study, based on the available literature and original analyses, takes into account the limitations resulting from the properties of the raw materials and presents the current state of possible commercial-scale uses of krill-processing technologies into products for human consumption, animal feed and industrial purposes. It also outlines views on marketing problems and on costs and prices of krill products already being produced or expected to be produced in the near future.

2. STOCK ESTIMATES AND CATCHES, FISHING TECHNIQUES AND DAILY CATCH RATES

2.1 Stock estimates and catches

Euphausia superba occurs in the belt of Antarctic waters between the minimum and maximum annual range of ice cover, south of the Antarctic Convergence; its distribution is circumpolar. The distribution of its biomass varies within this vast area.

Estimates of krill stocks in the Antarctic have varied greatly since 1973, as shown in Table 1.

Table 1

Krill Stocks Estimates

Author	Stocks (million tons)
Lyubimova, et al. (1979)	800 - 5 000
Marr (1962) as quoted in Everson (1977)	44.5
Marr (1962) and Heyerdahl (1932) as quoted in Everson (1977)	521
Gulland (1970) as quoted in Everson (1977)	750(375)
Doi and Kawamaki (1979)	1 200
Voronina (1983)	60 - 100
Kalinowski and Witek (1983)	100 - 400

The disparities in the estimates of the various authors are great, which may be the result of different calculation methods. Still, most authors agree that the stocks are not smaller than 100 and not greater than 500 million tons (Kalinowski and Witek, 1983).

In the 1980s, an international programme of krill research, BIOMASS, was initiated in the Antarctic; one of its objectives was to assess krill stocks by hydroacoustic methods. This project was based on two experiments, FIBEX and SIBEX. The first took place in 1981: krill stocks in various sectors of the Antarctic with a total area of 4.54 million km^2 were estimated at 78 million tons. However, this figure is still being debated by BIOMASS experts. If we were to assume that the distribution of krill is uniform and that the whole area of its occurrence equals 16.2 million km^2, krill biomass in 1981 in the whole Antarctic would have been 270 $\pm$ 48 million tons (Kalinowski, 1983).

The differences in krill stock estimates will most likely persist in the near future. Nevertheless, even the most conservative assessment will justify interest in this crustacean as an important source of protein of marine origin.

Determining total allowable catch is as controversial as stock assessment. The papers of Bogdanov and Lyubimova (1978) and some BIOMASS experts state that catching 10 per cent of the biomass should not disturb the ecological balance in the Antarctic. Mitchell and Sandbrook (1980) think that the allowable catch may constitute 2 to 5 per cent of the amount of krill at present consumed by whales. Gulland (1983) is of the opinion that at least 25 per cent of the estimated krill biomass may be caught.

To manage the fishery and conserve the living resources of the Antarctic, a Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) was signed in 1980. At a meeting of representatives of states participating in the Convention in September 1984 in Hobart, Australia, a group of experts stated that so far there had been no information on the impact of the krill fishery on the size of its biomass. However, it was recommended that a system of observation and inspection of fleets fishing for krill and Antarctic fish be created.

According to the FAO Yearbook of Fishery Statistics, Vol. 54, 1982, world krill catches in recent years have been the following:

1975	39 000 tons
1976	3 000 tons
1977	122 000 tons
1978	142 000 tons
1979	332 000 tons
1980	477 000 tons
1981	448 000 tons
1982	530 000 tons

In 1983 and 1984, the catches dropped to about 250 000 tons (according to information from the CCAMLR session, Hobart, 1984).

2.2 Krill fishing techniques

As is the case with fish, commercial fishing operationgs for krill are conducted at the sites of mass concentrations. Two types of krill concentrations have been observed: high-density shoals and scattered shoals. The phenomenon of concentration formation has not been fully explained yet, but it may occur mechanically at the boundary between water masses flowing at different speeds.

Like other pelagic animals living in shoals, krill undertake diurnal vertical migrations. At night, krill patches scatter and move upwards towards the surface. During the daytime, krill occur in dense patches below the euphotic zone. The majority of krill catches are made in the upper water layer (5-50 m), although shoals are also caught at greater depths (100-300 m).

Among the various types of fishing gear tested so far, the most effective was a pelagic trawl specially designed for this purpose. The proper strength of the trawl yarn was obtained by using a two-layer twine for its belly and codend. The outer layer is made

from thick strong twine with a large mesh, the inner layer from segments of thin yarn with a fine mesh. Depending on the kind of krill concentration (dense or scattered), different pelagic trawl designs should be used.

The low depths of trawling require the use of short trawling ropes which, together with low trawling speeds (2-3 knots), make it difficult to open the trawl horizontally.

Besides improvements in the design of the trawl netting, aimed at increasing its strength and reducing trawling resistance, new methods of hauling and emptying krill trawls are being tested. A krill trawling system, consisting of two trawls hauled in parallel, is being tried. It has been shown that it is possible in this way to reduce energy consumption and increase catch rates (Krepa, 1983).

Krill fishing techniques are generally similar to those for pelagic fish. Since krill are characterized by low resistance to mechanical damage, large single hauls are of little value as the raw material is badly crushed when the trawl is brought aboard. The time of its on-board handling becomes longer too. The long duration of hauls also results in weight losses. Efforts should be made to plan catches in a daily cycle so that single hauls do not exceed 5-6 tons and processing can be conducted in an unbroken sequence. The hydraulic pump method for emptying the trawl eliminates crushing during hauling aboard and reduces labour. However, this method has not yet been used in practice.

Proper hydroacoustic equipment is necessary to plan daily catch rates. This not only permits the location of krill concentrations and the determination of amounts in the trawl but also enables operators to distinguish concentrations of other organisms such as salps and jellyfish. In practice, planning and controlling daily catches according to the requirements of the throughput of the processing plant is not always possible; however, this is caused by the differences in yields of daytime and nighttime catches. Experience with Polish factory trawlers shows that 70-80 per cent of krill are caught during daytime (Krepa, 1983), although when krill shoals are scattered the differences between daytime and nighttime catches are much smaller. Surplus quantities of krill caught during the day can be used only for the production of animal feed because of spoilage of the raw material. Irregular supplies of raw material to the processing plant may also result from the nature of the fishing ground and weather conditions.

The experience gained so far by fishing vessels of various countries, including Poland, shows that it is not fishing capabilities that determine the present state and prospects for intensification of krill stock exploitation but problems related to processing and marketing.

2.3 Daily catch rates

Ice around the Antarctic is the main obstacle to fishing operations. It determines the length of the fishing season, which on average lasts from mid-November to mid-April. It may be extended to seven months or even longer when weather conditions are favourable. This has been confirmed by Polish vessels which conducted trials and fishing operations as late as the end of May.

Many factors influence catch rates, including types of krill concentrations, size of vessel and fishing gear, ice and weather conditions, processing capacity of the vessel, experience of the crew, etc. Catch results of a vessel are best expressed by mean catch per day fished, i.e., the size of actual catches during the whole stay on fishing grounds per day. In many publications, the daily catch rate was determined on the basis of practically attainable catch in tons per hour. This has led to the assumption of mean catch rate per day fished in the whole season at 100-150 tons or even more. The drawbacks of this method have been noted (Eddie, 1977).

In the present paper, the basis for calculating average daily catch rates was assumed to be catch results attained during the 1977 season by three Polish factory trawlers (see section 5). The results were confirmed by other Polish vessels in the years 1978 to 1983.

These vessels, aided by investigations of fishing grounds by the research vessel, PROFESSOR SIEDLECKI, conducted fishing operations in the Atlantic sector of the Antarctic

between meridians 0 and 90°W, near the fishing grounds of South Georgia, South Orkney Islands, Grahamland and in various parts of the Weddell Sea.

The three vessels caught a total of 8 033 tons of krill during 139 days of fishing, obtaining a daily catch rate of 57.8 tons per vessel (Fig. 1). Some hauls were as large as 10-20 tons in 30-60 minutes of trawling. Daily catch rates were sometimes so high that fishing operations had to be halted because the tanks and the decks were buried under krill. However, such yields were infrequent and untypical of daily average catch rates per vessel (Russek, Kasprzyk and Szostak, 1981).

For the calculation of various variants in the cost of krill processing on board, it has been assumed that daily average catch rate equals 55-60 tons and that the vessel remains on krill fishing grounds for 126-148 days, of which 106 days fished. These values may differ only slightly from those currently attained by vessels of other countries. This view is confirmed by the published cruise results of a large Japanese factory trawler (104.5 m length) in the 1981/82 and 1982/83 fishing seasons; it spent 144 and 134 days in the above-mentioned area of operations, the number of days fished being 115 and 118 respectively. Its average daily catch rate was 51.5 tons.

3. TECHNOLOGICAL ASPECTS OF KRILL AS RAW MATERIAL

It is a truism to say that all technological work should be preceded by the fullest possible examination of the raw material. Unfortunately, this was not the case in the first period of research in krill utilization. The fluoride problem may be cited as an example here since it hampered the development of technology.

The results of research on the chemical composition and technological properties of krill in world literature vary greatly. This is especially true as regards labile chemical components, such as protein, lipids and vitamins. This chapter presents only the results of those investigations and views that introduce new elements not included in Grantham's report (1977).

3.1 Chemical composition and biochemical properties

3.1.1 Protein, enzymes

No new important findings have been made in this field as there has been little research on fresh raw material. It has been confirmed that fresh krill contains a lot of water-soluble protein. The data presented in Table 2 are similar to those obtained by Kolakowski (1982), who determined the share of sarcoplasmatic proteins at 58 per cent of the whole, myofibrillar proteins at 17 per cent, and non-protein (N) at 21 per cent.

The large share of water-soluble protein in krill muscles has serious technological consequences: during peeling, it is necessary to spray the krill with water. This causes the extraction of protein from the muscles and, consequently, the lowering of yields. Research is being conducted to solve this problem.

Table 2

Amounts of protein in whole fresh krill and tail meat

(Shibota, 1979)

	Protein (per cent)	
	sarcoplasmatic	myofibrillar
Whole krill	6.1 ± 0.4	3.7 ± 0.4
Tail meat	5.0 ± 0.4	9.4 ± 0.8

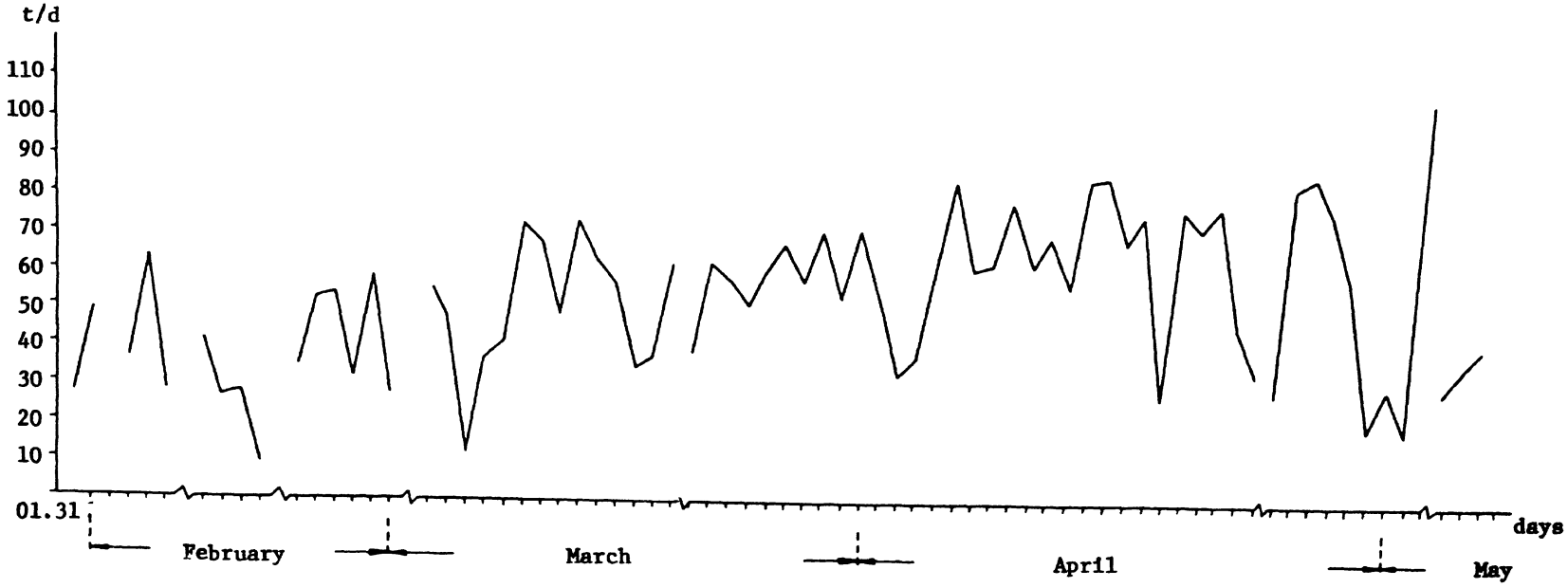

Figure 1. Average daily catches of krill for 3 vessels in 1977 (in tons)

The main difficulty in krill processing is caused by the very active system of proteolytic enzymes. During the hydrolysis of casein, they exhibit two wide activity maxima in the pH range of 6.5-7.5 and 9.3-10.4. In the pH range of 6-10.6, the activity does not drop below 80 per cent of the maximum activity (Galas et al.; Bobrovskaya, Kardashev and Vaitman, 1981). The activity of proteases depends on sex, age (size), physiological condition and feeding. All these factors play a role in the processing and storage of krill products. The activity is particularly high in immature specimens, which is explained by intensive metabolism connected with the growth of the animal (Mitskevitch and Mosolov, 1981). The use of special inhibitors has shown the presence of three types of proteases: serine proteinases, metal enzymes, and, to a lesser extent, SH-enzymes. These types can also be found in other invertebrates (Mitskevitch and Mosolov, 1981). During cold storage, proteolytic activity increases due to the diffusion of enzymes from the intestines to the muscular tissue, and the raw material becomes unfit for processing into food products. The shelf life of frozen krill at -18°C is only three months (Bidenko, Rasulova and Odintsov, 1981).

Konagaya (1980) has investigated the distribution of proteases in the krill body. He has found that over 95 per cent of protease activity takes place in the cephalothorax while the remaining 5 per cent in the tail part. That is why it is necessary to remove the contents of the cephalothorax by centrifugal action or pressing. This will considerably block autolytic processes in the raw material.

A large role is also played by very active lipases present in the digestive tract of krill, which cause the decomposition of phospholipids and, to a lesser degree, triglycerides. A result of their activity is an increase of free fatty acids (FFA) (Ellingsen and Mohr, 1981; Galas et al.,1979). The highest lipolytic activity is exhibited by krill with completely filled intestines (Bobrovskaya, Kardashev and Vaitman, 1981).

3.1.2 Lipids

The knowledge concerning krill lipids has grown considerably since Grantham's report. Table 3 presents the results of investigations of lipid contents in krill. It was confirmed that basic lipid classes include phospholipids and triglycerides as well as sterols and their esters. An increase in total lipids is accompanied by a drop in the phospholipid level and a rise in the level of triglycerides. There is an almost linear correlation between the contents of phospholipids and triglycerides and total lipid contents, which may mean that both groups play the role of an energy reserve (Ellingsen and Mohr, 1981).

Table 3

Percentage share of basic classes of krill lipids

(Rzhavskaya, 1981)

	Total lipids contents (per cent)										
	1.3	2.0	3.7	4.2	4.9	5.2	7.3	8.3	9.9	6.3[x]	3.4[x]
Phospholipids	34.6	31.3	29.2	19.9	20.8	18.2	22.0	24.3	13.4	12.8	31.0
Monoglycerides			2.6			3.0	6.2	2.2	2.0	2.4	8.6
Triglycerides	36.2	37.0	32.2	51.6	49.7	40.8	53.3	50.4	59.8	54.2	36.3
Free Fatty Acids	14.0	16.1	15.0	11.7	11.4	13.6	7.0	3.5	2.6	13.2	7.8
Diglycerides	8.3	9.6	2.8	9.6	10.8	3.2		2.8	0.9	4.0	3.4
Sterols			8.6			8.4	5.6	8.2	6.8	5.6	5.6
Steroid Esters	6.8	6.0	8.0	7.2	7.3	10.0	6.0	8.2	14.7	7.4	6.8

x feeding krill

The contents of polyunsaturated fatty acids diminish with an increase in total lipid contents. This is confirmed by industrial practice. The generally observed high contents of FFA (up to 31 per cent of total lipids) is, according to Ellingsen and Mohr (1981), a result of lipase and phospholipase activity. These enzymes continue to be active in raw material frozen at excessively low temperatures. According to these authors, the natural level of FFA in krill is about 4 per cent.

The presence of waxes was also observed in Euphausia superba (Sawicki, 1979; Rybalkina et al., 1981; Saether, Ellingsen and Mohr, 1983). These compounds are characteristic of Euphausia crystallorophias living farther south. Lipids concentrations in krill increase with age; after spawning, they rapidly decrease. Almost 70 per cent of lipids are located in membranes under the shell (Bidenko, Rasulova and Odintsov, 1981).

3.1.3 Fluoride problem

Table 4

Concentration of fluoride in Antarctic animals

Species	F ppm (dry weight)			Source
	Whole animal	Carapace/ bones	Muscle	
Euphausia superba - larvae	1 588			Hempel and Manthey (1981)
	2 400	4 260	570	Soevik and Braekkan (1979)
	1 950	2 840	325	Schneppenheim (1980)
	1 532		75	Christians and Leinemann (1980)
	1 470		42	Bykowski, Kostuch and Kowakzuk (1981)
			70-80	Christians, Leinemann and Manthey (1981)
			30-50	Christians, Leinemann and Manthey (1982)
	1 009		70	Boone and Manthey (1983)
			90	Bykowski and Dutkiewicz (1984)
Fish:				
Micromesistius australis		1 207	1.4	Oehlenschlager and Manthey (1982)
Notothenia gibberifrons		1 156	1.3	" " "
Notothenia rossii marmorata		964	2.2	" " "
Notothenia neglecta		865	3.7	" " "
Chaenocephalus aceratus		1 143	1.8	" " "
Champsocephalus gunnari		616	1.9	" " "
Seals:				
Lobodon carcinophagus		5 700	5	Schneppenheim (1980)
Penguins:				
Pygoscelis adeliae		7 350	13	Schneppenheim (1980)

The paper published by Soevik and Braekkan in 1979 had a considerable impact on earlier opinions concerning the possible uses of krill for human consumption and animal feed. Determining fluoride contents in the whole krill (up to 2 400 ppm) and its anatomical parts at a very high level, these authors stated that: "This would make krill in any form, even peeled, fail to comply with requirements for human consumption."

Numerous publications have since confirmed the high contents of fluoride in krill, even when compared with other animals from the Antarctic (Table 4). The papers of Christians and Leinemann (1980) and Christians, Leinemann and Manthey (1981) played a major role in explaining this problem. They proved that fluoride migrates from the shell to the muscle in frozen krill. The lowering of temperature to -40°C stops this process. By previously separating body fluids, the migration of fluoride during the frozen storage period may be reduced. Similarly, boiling of the raw material arrests the migration.

During the fifth Polish Antarctic expedition on the research vessel, PROFESSOR SIEDLECKI, in 1981, the pleon muscle of freshly caught krill was shown to contain about 40 ppm F (dry weight). A linear correlation between the contents of the shell and fluoride was also established. The assertion that over 90 per cent of fluoride are contained in the chitinous-mineral shell guided technological investigations. A technique for the production of meal with reduced shell contents was worked out and those for obtaining meat by the roller method and mince improved (Christians, Leinemann and Manthey, 1982; Bykowski, 1982).

However, the fluoride problem remains of interest to both biologists and technologists. The mechanism of its binding in the shell has not been fully explained, although it is associated with frequent moults of this crustacean (Bucholz, 1982). There are no papers on the remineralization of fluoride from the exuvia and dead animals or on the pathway of fluoride in the Antarctic food chain.

3.2 Changes in raw material before processing

The total number of bacteria in krill immediately after capture is very low, not exceeding several hundred to several thousand per gramme (Kelly, Lukaschevsky and Anderson, 1978; Ganowiak, 1979; Kartintsev, 1981). Therefore, the rapid changes in freshly caught krill are not of a microbiological character.

Immediately after death, interrelated biochemical changes take place, thus reducing krill's quality for processing. These include autolysis, which results in drip and unpleasant odour, as well as changes in texture and colour. Rigor mortis under average temperature conditions of the area (0-5°C) begins after one hour and lasts for two more. Freshly caught krill are brick red-pink to pink. Through the almost transparent shell, it is possible to see the green or colourless patch of the stomach. In the first two hours, krill become non-transparent, starting with the cephalothorax. The shell becomes shiny, the tail arched in a characteristic way. After 4-6 hours, the colour turns light pink, then light grey and the intestines become dark. Yellow-green fluid starts to drip from under the shell.

Longer storage causes flaccidity of the tissue, which becomes clammy; the shell is grey. After 12-16 hours, the bacterial decomposition of tissue begins. The main factor in those changes is the above-mentioned complex of proteases, concentrated in the cephalothorax. Unpleasant odour is also a result of enzymatic changes in phytoplankton, during which, among others, dimethyl sulfide is formed.

Blackening of the cephalothorax was earlier ascribed to the activity of tyrosinase, as is the case with other crustaceans. At present, this process is believed to be caused by catechol oxidase (Oshima and Nagayama, 1980).

Sensory investigations of general quality -- taste, odour, texture -- have shown that after 3-4 hours of storage at air temperature the intensity of those changes reaches such a level that the raw material is no longer fit for processing into food (Kolodziejski et al., 1979; Smirnov, Boydalinova and Andreev, 1981; Andreev, Bykov and Smirnov, 1981).

The intensity and progress of these changes depend mainly on two factors. Soviet scientists have proved that the raw material coming from large (10-15 tons) and long (1.5 hours) hauls has a much higher level of volatile bases after 3-4 hours of storage than that from small (up to 5 tons) and short (1 hour) hauls (Artiukhova and Kapitanova, 1981). With controlled hauls, this factor plays a much smaller role than the storage method before processing.

In commercial practice, two methods of storage are employed: "dry" storage on board or in tanks and in Refrigerated Sea Water (RSW) or seawater. The first method results in large amounts of drip as the delicate raw material is mechanically compressed, and a large loss of dry weight, including valuable components like protein. On the other hand, storage in RSW causes a strong extraction of water-soluble protein and the rise of salt contents. The amount of NaCl in krill doubles after four hours (Schreiber et al., 1981). The only advantage to this method is that it makes unloading from tanks easier and that the raw material does not lump so much.

In practice, the raw material is more frequently stored "dry" on board, often in layers of 50 cm. When krill density is about 0.9 t/m^3, a haul of 10 tons stored in 20 cm layers, which would avoid damage, would occupy an area of 55 m^2. This is not feasible on fishing vessels currently used.

A better understanding of the changes that take place in the raw material allowed a more precise formulation of storage principles. Storage time should be as short as possible; for krill for human consumption, it cannot exceed 3-4 hours; for krill for meal production, 8-10 hours. To keep within these deadlines, fishing techniques must allow for an adjustment of the haul size and the vessel must be properly equipped for processing, i.e., conveyor belts to shorten the passage of the raw material and tanks.

3.3 Factors limiting technological usefulness of raw material

3.3.1 Size

Because of the high proteolytic activity, immature krill of a length of about 34 mm should not be frozen. Their shelf life at $-18^{\circ}C$ is only one month when they are to be used in food production. That is why hauls consisting of 40 per cent of such specimens are used for the production of krill meal (Bobrovskaya, Kardashev and Vaitman, 1981).

The share of tail meat in krill changes with size. When krill of 35-46 mm and larger are peeled manually, the yield of meat increases from 25 to 32 per cent (Bidenko, Rasulova and Odintsov, 1981). A similar relationship was observed during mechanical krill peeling (Bykowski and Dutkiewicz, 1984). When producing canned products from the coagulated paste "Ocean", the quality of the product was lower when small krill (up to 35 mm in length) were used (Artiukhova and Kapitanova, 1981). After defrosting, the drip is much smaller in large krill than in small ones (Suzuki, 1981).

The problem of mechanical sorting of krill has not yet been solved, and grading trials have ended in failure. A question arises as to how to determine the size of krill so they can be utilized properly. Fast methods of approximate size measurements, which are based on the correlation between the length and the volume of specimens, have been worked out (Kolodziejski et al., 1979; Bidenko, Rasulova and Odintsov, 1981).

3.3.2 Amount of phytoplankton

Krill feed on phytoplankton, which is accumulated in the thoracic basket and the digestive tract. Phytoplankton is responsible for the colouration of the head section and cephalothorax and the deterioration of the sensory properties of the raw product. Intensively feeding "green" krill are unfit for processing into mince-type products (Bykov, 1981). Because of the chlorophyll contained in phytoplankton, the coagulated paste Ocean was green to grey in colour. Canned products made from feeding krill are of inferior quality (Artiukhova and Kapitanova, 1981). In Poland, on the basis of size and feeding conditions, three grades of krill, varying in technological usefulness, are distinguished (Table 5).

Table 5

Technological usefulness of krill depending on feeding condition and size (Kolodziejski et al.,1979)

Grade	Feeding condition	Size (in mm)	Technological usefulness
A	non-feeding	46	for all processing options
B	moderately feeding	37-46	for all processing options; for food production, gut removal is desirable
C	intensively feeding	46	unfit for processing into food; good for animal feed

3.3.3 Gut removal

The processing of krill with intestines and their contents causes a deterioration in the quality of products and may lead to disqualification. Gut removal is now believed to be necessary for processing krill into mince-type products. It may be accomplished either by centrifugal action or by gentle pressing. The result of both methods is similar, i.e., the gut and phytoplankton are removed. In addition, fat contents are reduced by about 30-40 per cent, which is desirable in certain technologies. The effectiveness of gut removal can be seen from the considerable reduction of enzymatic activity in the raw material (Kolodziejski, 1979).

3.3.4 By-catch problem

Krill processing is made more difficult by the presence of by-catch (salps, jellyfish, juvenile fish, fish larvae), which often constitutes over 20 per cent of the total catch in a haul. When processing krill into food products, it is therefore necessary to separate the by-catch manually and, in extreme cases, change the fishing ground.

4. ACTUAL POSSIBILITIES OF KRILL PROCESSING

4.1 Frozen, boiled-frozen and dried krill

With the exception of Asian markets, the prospects for the sale of frozen or boiled-frozen krill are not very promising. Nevertheless, such products were successfully marketed in the USSR as feed for fur animals. Only krill stored "dry" before freezing may be used for this purpose; raw material stored in RSW acquired such a high level of salt that it could not be used.

In some Asian countries (Japan, South Korea, Taiwan), where euphausiids are a traditional food, a lot of attention was devoted to frozen krill. By using various polyphosphates and sodium erythorbate, attempts were made to stop quality changes in krill after defrosting (Jiang, 1980). In Japan, large krill with eggs are considered a delicacy. They must be boiled for approximately 5 minutes at 90°C before freezing so that no blackening and autolysis occur after defrosting. The product is frozen individually (IQF) and glazed, or frozen in blocks and glazed. During boiling, substances that would produce unpleasant odours after defrosting are emitted. These are usually such compounds as carbonyl, aliphatic hydrocarbons and dimethyl sulfide. A distillate with water vapour contained a lot of pyrazine (Kubota et al., 1980, 1981). However, the loss of the distinctive odour may be considered a drawback in some parts of Asia.

Dried euphausiids, including Antarctic krill, are also a popular food in Asia. The Japanese prefer dry to fresh krill. When partially dried (about 50 per cent of water), the product must be stored below 0°C. Such a product has better texture and smell than that dried completely. Gut removal is recommended before drying (Suzuki, 1981).

4.2 Minced products

In the first phase of work on krill processing, the aim was to develop a simple technology that would produce large quantities of quality items. In the USSR, Poland, the Federal Republic of Germany and South Korea, the interest concentrated on such products as coagulated paste,and mince.

4.2.1 Coagulated paste

The first food product to appear on the Soviet market, and later in other countries, was a coagulated paste named "Ocean". It was first produced on-board Soviet vessels and on land on AKP Vniro production lines. The throughput of this line was about 1 000 kg of krill per hour; the yield depended on the size of krill and varied between 30 and 40 per cent.

The production process consisted in pressing out protein juice from krill by means of a screw press, thermal coagulation of the juice, separating coagulated protein from the liquid, cooling of the paste, freezing and packaging. Although the process seemed simple, the resulting product had a number of serious drawbacks, due to the still little-known properties of the raw material and the shortcomings of technology. The main factor, which has caused the reduction of production in the USSR and halted work on method improvement in Poland and the Federal Republic of Germany is the low sensory quality of the product. Furthermore, the paste was produced from "green" feeding krill, which caused a discolouration of the product from green to grey, an unpleasant smell and a grassy taste (Bykov,1981).

To satisfy sensory and health requirements, it is necessary to perform some additional operations, e.g., separate the shell, which contains most of the fluoride. The best separation is obtained with Baader or Bibun separators(diameter of drum opening: 0.8-1.2 mm) or separator-desludger centrifuge systems.

The temperature of coagulation is a major factor in the quality of the product. Optimum temperature is believed to be 80-90°C; higher temperatures cause the blackening of the paste (Artiukhova and Kapitanova, 198; Schreiber et al., 1981). The coagulated mass should be quickly cooled. Cooling by means of screw conveyors with water jacket brings poor results. Quick cooling to a temperature of 10°C within 1-3 minutes may be done in a "flash cooler", used in a prototype line of Norwegian production (Rieber and Son). To get rid of unpleasant smells during boiling, it is necessary to separate the thermal drip as accurately as possible. This may be achieved on vibrating or rotating screens or decanters. Before packaging, the product should be homogenized to achieve uniform colouration and split up lumps of coagulated paste.

Product characteristics

According to Soviet data, the highest quality of coagulated paste is made from raw material coming from 10-ton hauls, processed within two hours of capture. The product is then pink to dark pink and has a grit-like consistency resembling curds. It also has a characteristic intensive shellfish taste and smell. The coagulated paste produced from raw material of inferior quality, i.e., stored for more than two hours, smells of fish meal (Artiukhova and Kapitanova, 1981).

The chemical composition of coagulated paste changes considerably according to the quality of the raw material and the parameters of the process (Table 6). The biological and nutritive value of coagulated paste is high and comparable to fish (Table 7). According to Soviet standards, the shelf life of coagulated paste at -18°C is 12 months.

Product options

The USSR has the widest experience in marketing coagulated paste, which has been sold there for ten years. At the end of the 1970s, 2 000 tons per annum were being produced; at present the quantity is smaller (Karnicki, 1979). Although many recipes were prepared (canned products, paste, salads, shrimp butter, cheese with paste), the problem of marketing in the USSR was not really solved. In Poland, the sensory properties of coagulated paste produced on-board fishing vessels were considered low. Several products were made in which the share of coagulated paste was over 10 per cent;their quality was considered satisfactory (Brzozowska et al., 1979).

Table 6

Chemical composition of krill mince products (per cent)

	Dry mass	Crude protein	Lipids	Ash	Shell	Source
Coagulated paste	26.2±0.4	16.7±0.2	6.6±0.3	1.8±0.01	0.46±0.02	Markowski(1979)
	26.3	15.6	6.3	2.8	-	Schreiber et al. (1981)
	25-35	14-20	3-10	1.7-3.0	-	Lagunov et al. (1981)
Mince	25.2±0.3	14.2±0.2	8.7±0.6	-	0.39±0.02	Markowski(1979)
	23.1	13.3	5.0	-	-	Schreiber et al. (1981)
Precipitate	26.6-28.8	18.1-19.7	4.5-7.0	-	0.02-0.07	Kolakowski et al. (1984)

Table 7

Biological value of krill paste and mince

(Piekarska et al., 1979)

	NPU	PER	Pepsin digestibility
Coagulated paste	84	2.82	91.3
Mince	75	2.66	89.6

4.2.2 Krill mince

In 1978, a technique for producing krill mince was worked out simultaneously in Poland and the Federal Republic of Germany. It differed from the coagulated paste process in that the raw material was precooked. Larger quantities of raw material for production could be stored because precooking permits longer storage. The yield of the process was high, equalling 50 per cent and 40 per cent for the raw material subjected to gut removal. The Polish process made use of a two-stage shell separation. Coarse separation was achieved in a separator with a drum opening diameter of 3-4 mm and fine separation, in a drum equipped with a double screen with an opening diameter of 0.5-1 mm. However, krill mince was never produced on a commercial scale in Poland.

Product characteristics

Krill mince is a dense pink paste. The colour turns brown if the raw material was of inferior quality. The mince has an intense shellfish smell and sweet shellfish taste. Its sensory quality was considered rather good but not outstanding. Table 6 presents the chemical composition of mince. Biological value indices (see Table 7) are slightly lower than those of coagulated paste.

Utilization

Because of its functional properties -- low ability to emulsify fats, inability to bind water and high pH contents -- krill mince is of limited usefulness. In Poland, dishes made with up to 10 per cent mince met with approval, although their evaluation was lower than that of the same dishes made with coagulated paste (Brzozowska et al., 1979). A large number of recipes with mince was prepared in the Federal Republic of Germany, including fermented sausages, soups, etc. (Christians, 1980; Schreiber et al., 1981).

4.2.3 Krill precipitate

An original process for making krill precipitate, a product resembling krill mince, was patented in Poland (Kolakowski, Fik and Gajowiecki, 1977). The process is based on the use of krill's own enzymes (Kolakowski et al., 1980, 1980a; Kolakowski and Lachowicz, 1982). The autoproteolysis of krill muscle proteins carried out in controlled conditions (temperature about 50°C; pH 6.9-7.4) causes rapid hydrolysis of proteins. Fine-particle products, which cannot be thermally precipitated, are formed. In this technology, controlled autoproteolysis causes accelerated extraction of proteins and results in the reduced viscosity of the krill-water mixture. This allows for a good separation of liquid parts from the shell in a desludger centrifuge (Kolakowski et al., 1984). The liquidized protein phase is thermally coagulated at about 90°C for 3-4 minutes, homogenized and frozen in blocks.

In 1983, semi-technical trials to produce precipitate were made on a Polish factory trawler. The parameters of the autoproteolysis process were defined more precisely (Table 8). The yield of the product was 425 kg per 1 000 kg of raw material. The basic composition of the precipitate is presented in Table 6. The main advantages of the process are the high degree of shell separation, thus a low level of fluoride, the high throughput and very low energy consumption. The product obtained is pink-red, has a slight shellfish smell, good taste and the consistency of curds. Product options are similar to those of mince products.

Table 8

Parameters of autoproteolysis process

(Kolakowski et al., 1984)

Variant	Gut removal	Krill/water	Temperature °C	Time minutes	1/minutes
A	+	3:1	35 ± 5	30-45	45-65
B	+	no water	35 ± 5	60-75	45-65
C	-	6/7:1	30-45	45 ± 15	60-70
D	-	no water	40-45	60 ± 15	50-60

4.3 Whole tail meat

According to specialists from many countries, tail meat is the most valuable krill food product while being the most difficult to obtain. Grantham (1977) wrote: "It is likely that highest value products obtainable from krill will be based on shell-free intact tail meats". Towards the end of the 1970s, a significant development in techniques and equipment for the production of shell-free meat took place. The leading countries doing research in this field were Denmark, Chile, Japan, Poland, the Federal Republic of Germany, the US and the USSR. Research resulted in three main methods for the production of meat: roller peeling, attrition of boiled-frozen krill, crashing of boiled krill and flotation of shells.

Equipment and procedures were worked out for each of these methods. Work on certain constructions was halted as the end product was of low quality, while other projects are still at the prototype testing stage. Krill meat and its products have appeared on the markets of some countries although in relatively low quantities. A general evaluation of the advancement of work on methods and equipment for the production of krill meat is difficult as publications dealing with this question are scarce.

4.3.1 Roller peeling

Krill peeling by the roller method consists in drawing the shell into a slit between two rotating rollers. Friction forces the muscle from the shell which, together with the head part and intestines, is removed through the slit as waste. The meat remains in the slit and falls out at the end of the rollers. The surface of the rollers must be sprayed with water.

In the years 1975-1979, attempts were made in Chile, Poland and the Federal Republic of Germany to use the Laitram and Skrometta shrimp-peeling machines for krill. However, tests showed that this equipment was unfit for krill; the low throughput and large dimensions made its use on-board fishing vessels impossible (Schreiber, 1981; Bykowski, 1982). In any case, these tests inspired a new approach to krill peeling.

Equipment and its parameters

Japan, Poland and the US have built machines of smaller dimensions and weight but with larger throughput than the shrimp-peeling machines tested (see Fig. 2). The differences among them include the direction of raw material flow (along or across roller axes), diameter and material of the rollers, kind of revolution (constant or reversible), the presence or absence of a cleaner panel, method of supply and raking of the raw material on the rollers. The peeling rollers are made of stainless steel and polished, or one roller is covered with rubber or plastic. Their diameter ranges from 25 to 65 mm in length, from 450 to 1 200 mm. The slit between the rollers varies from 0.1 to 0.5 mm. The rotation may be constant or reversible, the angle of rotation equals in this case 240°. The rpm may be adjusted from 27 to 200. The angle of roller inclination is between 9° and 30°. The numbers of rollers in one panel varies from 10 to 30. The panels are mounted in tiers and their number ranges from 3 to 4.

In 1979, prototype machines constructed by the Laitram Company (US) and the Sea Fisheries Institute (Poland) were tested on the Polish research vessel, PROFESSOR SIEDLECKI. The test results indicated unsatisfactory throughput and high shell content in the product. The perpendicular flow of krill with respect to the rollers, used in the American machine, resulted in low effectiveness of peeling. There is no information about further improvements in this construction. The Polish machine was improved during subsequent cruises. At present, the Dalmor Deep-Sea Fishing Enterprise in Gdynia, Poland, ordered a series of these machines from the Techmet company in Gdansk. Several firms in Japan have also constructed krill-peeling machines based on the roller system.

The size of the existing prototypes is smaller than that of shrimp peelers. For example, the Japanese machines measure (L x B x H) 100 x 1 100 x 800 mm and 1 750 x 1 200 x 1 800 mm; the Polish machine 1 600 x1 400 x 1 800 mm. A krill-peeling line also includes auxiliary equipment: pumps, raw material feeders, conveyor belts. Thus, the surface area occupied by the whole line is two times larger than the peeler itself. Still, it is

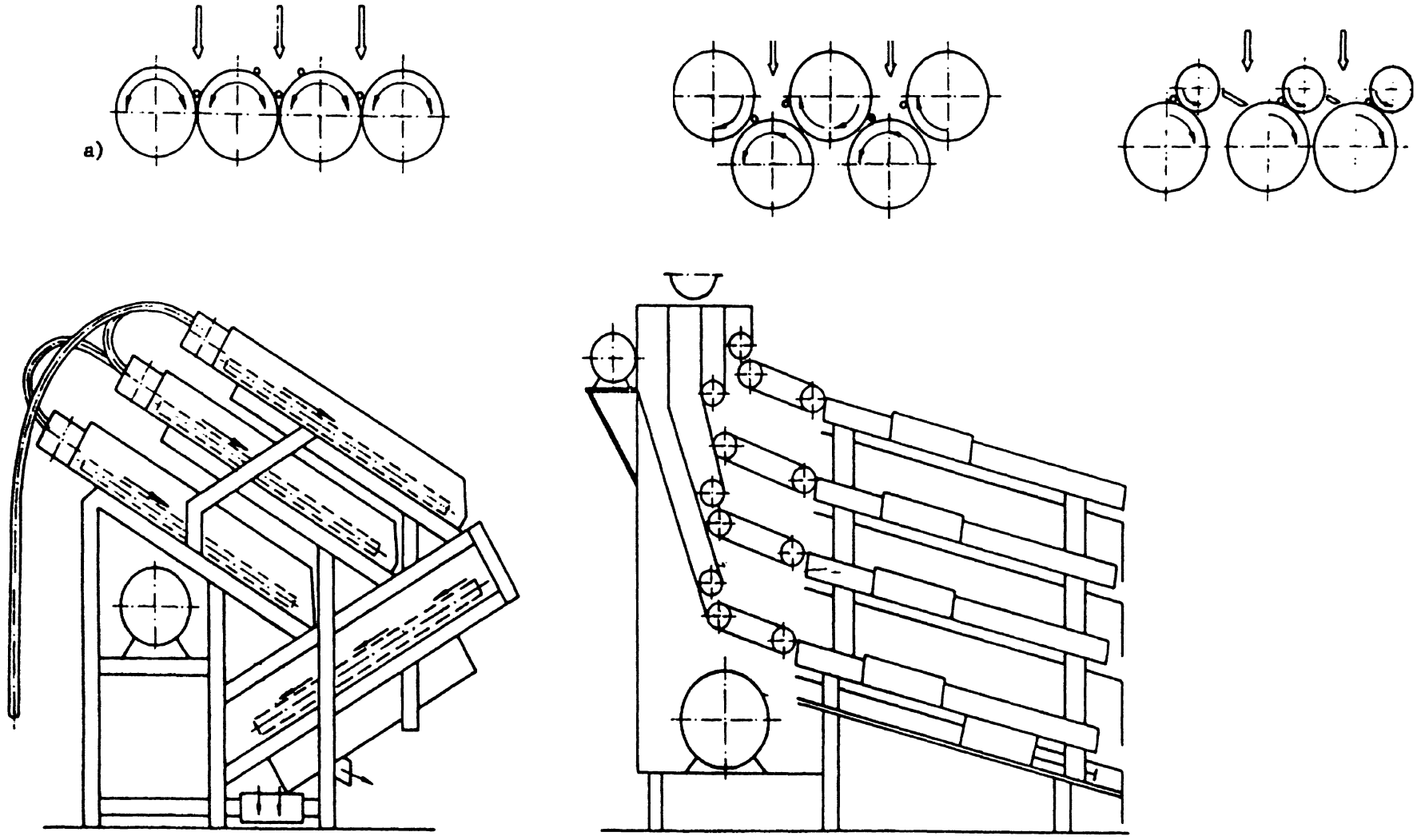

Figure Diagram of krill roller-peelers

a) Polish made; b) Japanese made

c) roller system with constant direction of revolutions, used in other constructions

possible to install 6-8 peelers with auxiliary equipment on a typical factory trawler. The consumption of seawater for one peeler is 200-3 000 litres per hour, and it is necessary to rinse the meat in fresh water (ratio 1:1). The peelers are driven by engines with a total power of about 2.5 kW. The machines require limited maintenance and only periodic adjustment.

Throughput and yield

The throughput of the existing machines ranges from 350 to 400 kg/h according to Japanese data and from 350 to 500 kg/h according to Polish data (Bykowski and Dutkiewicz, 1984). This depends on the size of krill and their freshness as well as on the technical characteristics of the peeler (number of rollers and of panels). The yield of meat is 10-25 per cent, depending on the size of krill. The manner of feeding the raw material into the peeler also has a great influence on the yield. In the product obtained on Polish machines, the shell content is below 0.1 per cent, i.e., below 100 ppm of fluoride in dry weight of meat. The degree of peeling, measured by the level of shell content in the product, depends on the strength of binding between the shell and the muscle. In order to weaken these bonds, it is necessary to introduce an additional operation called conditioning before peeling. Continuing research on this problem is aimed at improving the quality of the product and increasing productivity.

Product quality

Raw meat is glassy and light pink; it has a nice smell, springy texture and a sweet shellfish taste. After rinsing in fresh water, it remains slightly salty (Schreiber,1981). After blanching, the meat contracts so that it is the size of elongated rice grains; it is whitish-pink and has a slight shellfish taste and smell and firm texture (Table 9). Its chemical composition is presented in Table 10. Its aminoacid composition is very well balanced. Due to the low level of lipids, the product may be stored at a temperature of -25°C for 12 months. The meat contains 5-7 per cent more water than the raw material, which is connected to its high water-holding capacity. This results in large amounts of drip losses during defrosting (about 33 per cent of drip with respect to weight) and blanching. The meat is fit for consumption after heating it to about 50°C. Higher temperatures cause deterioration of sensory properties, especially taste, smell, texture, as well as increased drip (Bykowski and Kolodziejski, 1983).

Table 9

Sensory evaluation of various kinds of krill meat

(Bykowski and Dutkiewicz, 1984; Dunajski and Grabowska, 1979)

	Method		
	attrition	crashing	roller-peeled*
Appearance	light pink; easily noticeable granules, with cephalothorax and digestive tract remnants	white to light-pink; absence or presence of eye and shell fragments	white-pink; small, whole muscles with signs of contraction
Taste	salty, shellfish-like	neutral	sweet-sour, shellfish-like
Smell	shellfish-like; resembling boiled seeds of leguminous plants	not or weakly perceptible shellfish- or seaweed-like	of little intensity, weakly perceptible, resembling boiled egg
Consistency	delicate, soft; first impression of succulence gives way to fibrous-cottony one	difficult to bite and chew, low succulence	compact, elastic, delicate, succulent

* after blanching at 50°C

Table 10

Chemical composition of krill meat obtained by various methods
(in per cent of wet weight)

(Dunajski and Grabowska, 1979; Markowski, 1979; Bykowski et al., 1980)

	Method		
	roller-peeled	attrition	crashing
Dry weight %	14.0-16.0	19.0-24.0	23.1-28.6
Protein (Nx6.25) %	12.0-14.0	13.3-16.6	20.5-22.8
N_{np}/N_{tot}	0.17-0.21	0.14-0.15	0.02-0.03
Lipids	1.0-1.1	2.9-4.6	1.8-2.1
Ash	1.3-2.3	1.8-2.9	1.3-1.5
Chlorides	1.1-2.1	1.6-2.4	0.8-0.9
Shell	0.1-0.2	0.4-0.6	0.08-0.28
F mg/kg	15	90	35

Product options

Tail meat proteins preserve their functional properties (ability to emulsify fats and form gels) after defrosting. Thus, the meat may be used for a variety of products, and may be mixed with fish or shellfish meat and/or mince. The meat itself may be mechanically formed without binding substances (Anon., 1983). Polish krill meat was used in the US for a variety of products whose quality was considered high: fishburgers with krill meat added, casseroles, stews, soups, sauces, pâtés. In Poland, canned shrimp-like meat in brine was made; it was highly appraised also by Soviet scientists (Bykowski and Dutkiewicz, 1984). Krill sticks cut from frozen blocks and breaded were highly evaluated in Chile, the Federal Republic of Germany and Poland (Grantham, 1977; Schreiber et al., 1979). In Poland, a very tasty cocktail resembling the shrimp one was made from krill meat.

4.3.2 Peeling by attrition

This peeling method has been used in Japan, Poland and the USSR. In Japan, the shell was split by smashing individually frozen krill against tiny elements in a low-temperature chamber. In the USSR, the product was obtained by attrition of boiled-frozen krill against rough walls of the machine. A similar method was used in Poland. Attrition of the shell from fast-frozen (individually or in blocks) boiled krill took place on rotating discs and perforated walls of the machine casing. Thrown by the centrifugal force from the discs onto the walls, krill moved downward and the shells were removed by an air exhaust system. This machine constituted the main part of the production line; its throughput was 500 kg of raw material per hour, the yield 18-25 per cent. The drawback of this method was that attrition, the sorting of the granules and the packaging had to be done at a temperature of $-18^{\circ}C$. Attempts to behead krill before the operation, which would have improved the quality of the product, failed. At present, there is no information on further research into attrition-based methods of krill peeling.

Product quality

The product obtained by this method has the form of granules resembling beans but smaller and white-pink. There are about 6 000 granules per kg. Meat from krill boiled in fresh water has an intense shrimp-like, sweet taste (Table 9). Since whole krill are subjected to attrition, about 25 per cent of the granules contain remnants of the cephalothorax. Despite thermal treatment, some enzymes contained in the cephalothorax remain active. Oxidases cause blackening of the granules after defrosting and deep oxidation

changes of lipids. As a result, the product maintained its quality only for three months of storage at -25°C (Bykowski et al., 1980). The use of different packaging and anti-oxidants did not improve product stability (Bykova, Radakova and Kartintsev, 1981).

Product options

The protein of krill meat is fully denaturated because of boiling prior to attrition. Therefore, its use for further processing is very limited. In practice, it can only be a component of salads or cocktails and this is how it has been served in restaurants in the Soviet Union.

4.3.3 Meat separation of boiled krill by shell flotation

In 1978-1980, an experimental krill-peeling line with a throughput of 300 kg/h was installed at the Dalmor Enterprise in Gdynia. The shell of the boiled raw material was loosened in a special machine. This had a disc rotating at 1 200 to 2 000 rpm and a stationary crown (Fig. 3). Steam-boiled krill was fed into the centrifuge and thrown onto the rods of the stationary crown. The process loosened the shell and further separation took place by water flotation, repeated two or three times. The yield of the product was about 10-15 per cent and depended, among other factors, on the size of krill.

The shell may also be separated from the muscles of boiled krill in a high-pressure water or air jet. This method also makes use of flotation for the separation of shells. Tests of this kind are being conducted in the USSR and believed to be promising.

Product quality

The product obtained by the Polish technique consisted of small white granules (24 000-26 000 per kg). The chemical composition of the frozen product is presented in Table 10. As a result of boiling and repeated flotations, the product is totally devoid of flavour and smell (Table 9). Because of the very low level of lipids, the meat does not exhibit any signs of rancidity, even after long frozen storage. Thermal denaturation of protein makes the product of little use for further processing. It does not form gels or emulsify fats. If heated to over 90°C, it emits an unpleasant odour and undergoes discolouration. It has been found that the addition of 13 per cent of krill meat (converted into protein) to fresh pork or beef results in stable emulsions. Good-quality, sausage-like products may be obtained from them (Dunajski and Grabowska, 1979). There is no information on the sensory qualities of meat obtained by this method in other countries. However, there are good-quality canned products in brine on the Soviet market.

4.4 Concentrates and other food products

At first, it was believed that protein concentrates should be one of the main krill-processing options. Work in this field was conducted in Japan, South Korea, Poland, the Federal Republic of Germany, Norway and the USSR, but these investigations did not go beyon the laboratory stage. The use of flammable solvents for extraction makes production at sea unrealistic, and it seems that this option is not very promising at present.

Fermented protein sauces are an interesting product, especially for certain Asian countries. Using frozen krill and ethanol as an antiseptic, the Koreans obtained good-quality sauces (Park et al., 1980a).

4.5 Krill meal

In the beginning of worldwide interest in krill, it was believed that krill would be used mainly for the production of high-protein animal feeds. The difficulties in food processing seemed too great. There have been no major changes in meal-processing technology since the report of Grantham (1977). Despite the increase in catches, no special equipment for the production of krill meal was constructed; only slight modifications of the existing meal plants were made. However, the commercial-scale production of meal permitted the improvement of the process and the definition of the parameters, properties and utilization options of krill meal.

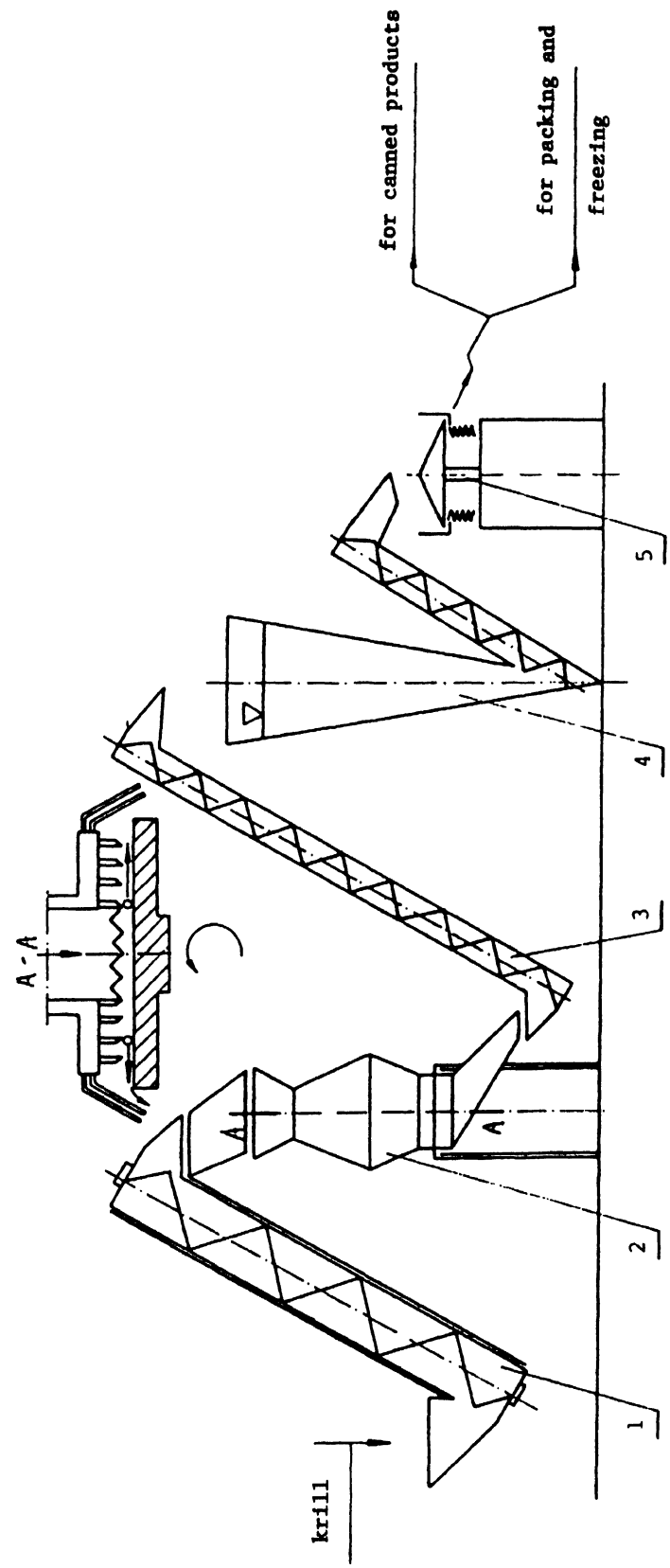

Figure 3. Diagram of krill tail-meat production process by disintegration and flotation elaborated at Dalmor, Gdynia. 1. Cooker; 2. Centrifuge for freeing meat from shell; 3. Screw conveyor; 4. Flotation equipment; 5. Vibrator for separating excess water from meat

4.5.1 Technological problems, modifications of the process

In industrial practice, a traditional method of krill-meal production is being used: cooking and pressing or centrifuging and drying. The production process in the existing plants was mastered very fast. However, krill technological properties, so different from those of fish, create certain problems which should be solved to improve production efficiency.

The goal is to increase the yield of the process which, in theory, equals 22-23 per cent but in commercial conditions is only 14-15 per cent (Bykowski, 1982). The yield diminishes with an increase in the storage time of the raw material before processing, since considerable losses of dry weight occur at this stage. Depending on the storage method, physical properties of krill change. The raw material stored on board becomes sticky after a few hours. This causes the blocking of machines (e.g., screw conveyors) and, consequently, a decrease in their throughput. Krill stored in seawater loses large quantities of nitrogen substances due to extraction. It also acquires a high level of salt; such meal is unfit for feeding broilers, for instance. Because of the loss of dry weight, it is assumed that krill should not be stored for longer than 8-10 hours. Efforts should be made to regulate catches so that the time before processing is as short as possible. As is the case with food products, krill for meal should be as fresh as possible. Storing of the raw material in the buffer hold of the plant should be kept to a minimum since the temperature there (often over 20^{o}C) accelerates autolytic processes, further increasing drip and dry weight losses.

The second factor determining the yield of krill meal production is cooking temperature. On the basis of model-based and commercial trials, the optimum temperature is believed to be 80-85 ^{o}C (Kolodziej et al., 1979; Maksimov et al., 1981; Reinacher, 1978). Such temperature stabilizes the dry weight in stick waters. When processing krill of inferior freshness, cooking temperature should be lower. When heated, krill behave differently than finfish: krill proteins coagulate, stick to the heated surfaces and lump. This causes the lengthening of the cooking time; it is also necessary to increase temperature by the use of directly injected steam, which requires increased consumption of fresh water, a scarce medium on most fishing vessels (Krepa, 1983). In Poland, more trials have been conducted to modify cooking by preheating the raw material in hot stick waters. The cooker design was also changed to avoid blocking by lumps of coagulated mass. An interesting solution that could replace traditional krill cookers in meal factories is a flow heat exchanger such as Contherm, produced by Alfa Laval.

Another operation that may cause losses of dry weight is the incomplete separation of stick waters from press cake or desludger residue. In commercial practice, stick waters are not utilized since no evaporators are used on-board fishing vessels. The amount of water in the press cake or residue after desludger centrifuge is closely connected with drying conditions. The use of higher temperatures causes decomposition of astaxanthin as well as changes in proteins, measured by the degree of availability of lysine.

At the end of the 1970s, a modified technique to produce krill meal with reduced shell content was worked out at the Sea Fisheries Institute, and tested under commercial conditions (Bykowski et al., 1980). An additional operation of mechanical shell separation was added to the traditional method. Using "neo-press" type separators with a perforated drum (holes of 1.2 mm diameter) such as the Baader 695 and Polish 01AK1, about 50 per cent of shells were removed (Bykowski, 1982). Further development of this method allows for a very precise shell separation and the product obtained contains only small amounts of shell (Table 11). These investigations were conducted on a fishing vessel but only on a laboratory scale. The problem that still awaits solution is the high fat content in krill meal. With typical centrifuges installed on fishing vessels, even with a number of additional operations, it has not been possible to separate krill oil mechanically. This is probably connected with the nature of protein-lipid bonds in the raw material.

Table 11

The composition of krill meal (per cent)

Kind of meal	Moisture	Protein	Crude fat	Ash	Shell	F ppm	Source
Whole krill	6.6-10.8	50.0-55.2	8.1-20.8	11.7-14.2	11.7-15.1		mean range from Polish data
	8.4	52.6	16.0	12.9	13.4	1 800	
	10.6	54.4	12.4	13.6	8.4	-	Grantham (1977)
	14.3	51.4	11.1	10.5	-	-	Mrotchkov et al., (1981)
	10.0	54.2	15.5	12.9	-	-	McElroy (1982)
Low shell	6.3	54.6	15.0	-	6.0	785	Bykowski (1982)
"Super" low shell	7.5	62.7	23.5	-	1.3	200	Bykowski (1982)

4.5.2 Product characteristics

Krill meals exhibit certain properties that distinguish them from fish meals. The volume weight of meal made from whole krill is 450-550 kg/m^3, low shell meal, 600 kg/m^3. Even when using the same equipment for production, krill meal is much more fine-grained than fish meal. The share of particles smaller than 0.3 mm in krill meal reaches 90 per cent. Even with up to 20 per cent fat content, krill meal does not lump. It is a highly hygroscopic product: krill meal with a water content of 5.3 per cent contained as much as 11.5 per cent after 10 months of storage in a non-air conditioned storehouse (Horbowska, Matyka and Dobrzycka, 1979).

The colour of meal depends on the quality of the raw material and the parameters of cooking and drying, changing from light red through pink to light beige and beige. The red-pink colour is caused by the presence of carotenoid compounds (astaxanthin and its esters). The discolouration is a result of their decomposition during production and storage; their quantity decreases from an initial 190 µg/g of meal to 55 µg/g after seven months. After 13 months, no pigment was observed. The odour of krill meal is typical of meals made from shellfish. During storage, its intensity decreases so that it resembles the smell of fish meals (Kolodziej et al., 1979; Tanaka, Katayose and Katayama, 1981).

Table 11 shows the basic chemical composition of krill meals. The large differentiation in the contents of lipids and nitrogen substances is a result of changes in the composition of the raw material, its freshness before processing, and the parameters of the production process. The aminoacid composition of krill meals, compared with FAO standards, is correct (Table 12).

Pepsin digestibility ranges from 76 to 90 per cent and is lower than that of fish meals (Horbowska, Matyka and Dobrzycka, 1979; Boeva, 1981; Rehbein, 1981).

Data concerning the biological and nutritive value of krill meal is presented in Table 13. It equals 3-4.5 Kcal/g while, according to Polish investigations, it is most frequently 4.2 Kcal/g. This is connected with the very high fat level in the product, equalling as much as 20 per cent. The lipids of krill meals are characterized by a high degree of unsaturation, which suggests their susceptibility to oxidation. Extensive investigations conducted at the Sea Fisheries Institute on various types of meal have shown

that they are stable for 13 months of storage without addition of antioxidants. During Antarctic expeditions and commercial catches conducted by several countries, including Poland, the self-ignition of krill meal was observed. To this day, this phenomenon has not been fully explained. However, our observations show that, to avoid it, it is important to cool the meal after production to about 20°C, provide good ventilation of the hold, and avoid excessive drying of the product.

Table 12

Comparision of the aminoacid content of krill meals and fish meals

(Horbowska, Matyka and Dobrzycka, 1979; Rehbein, 1981; Miller, 1971)

Aminoacid	Crude protein (in per cent)			
	Krill meal		Fish meal (Miller, 1971)	
	(Horbowska, Matyka and Dobrzycka, 1979)	Rehbein (1981)	Herring	White fish
Asp	9.55	9.86	9.1	8.5
Thre	3.84	3.97	4.3	3.9
Ser	3.79	4.08	3.8	4.8
Glu	12.52	12.68	12.8	12.8
Pro	4.12	3.98	4.2	5.3
Gly	4.00	4.86	6.0	9.9
Ala	4.68	5.43	6.3	6.3
Cys	1.03	1.26	1.0	0.9
Val	3.95	5.32	5.4	4.5
Met	2.55	2.54	2.9	2.6
Leu	4.34	4.87	7.5	6.5
Iso-leu	6.97	7.47	4.5	3.7
Tyr	3.73	4.02	3.1	2.6
Phe	4.36	4.83	3.9	3.3
Lys	7.62	6.54	7.7	6.9
His	2.51	1.92	2.4	2.0
Arg	6.32	5.81	5.8	6.4
Trp	1.02	nd	1.2	0.9

nd: not determined

Table 13

Nutritive and biological value of krill meal

(Krasnodebska, Hanczakowski and Korelewski,1979)

	BV	Pepsin digestibility	NPU	PER
Krill meal	64.2	98.9	63.5	2.93
Fish meal	70.1	94.8	66.5	1.93
Soya meal	66.4	92.0	61.1	2.69*

* with methionine

4.6 Chitin and chitosan

The krill shell is built of mineral compounds and chitin, bound with proteins. Depending on its biological condition, de-proteinized shell contains 30-40 per cent of chitin. Converted into fresh raw material weight, the amount of chitin is about 0.8 per cent (Yanase, 1975). Many technologies produce large amounts of shell waste (as much as 30-40 per cent of the raw material). These have a dry weight value of 24-35 per cent and contain large amounts of lipids, proteins and carotenoids. For these reasons, the traditional method of obtaining chitin from shrimp shells had to be modified (Brzeski, 1982). In a pilot plant of the Sea Fisheries Institute, several tons of chitin from krill were produced, using a specially developed technique. The production process consists of several operations: grinding and defrosting of shell blocks; mixing of shell waste with water at a ratio of 1:3; centrifuging of shells:about two hours of mixing with water and centrifuging reduces the amount of nitrogen compounds by about 30 per cent and that of lipids by 10-30 per cent; demineralization with a 3.5 per cent hydrochloric acid solution for two hours at a temperature of 20°C; short-time extraction of lipids with ethyl acetate; deproteinization with a 3.5 per cent natrium hydroxide solution; washing with fresh water; drying at a temperature of about 80°C. The yield of the process is about 58 per cent with respect to chitin contained in the shell. The final product contained up to 3.3 per cent of ash and was creamy to light pink.

By deacetylation of chitin (a 50 per cent solution of sodium hydroxide, temperature of 80-96°C, 15-30 minutes), chitosan was obtained. Its yield with respect to chitin was about 70 per cent (Brzeski, 1982).

Considerable research has been done in the past five years on production technology and possible industrial application of chitin/chitosan and its derivatives.

The Third International Conference held in Ancona, Italy, in April 1985 clearly indicated that research has reached the level when the industry must get involved to provide necessary impact for further development.

It was therefore noted with interest that the world leading alginate producer, PROTAN, from Norway has become involved in the commercial production of chitosan and its derivatives, and that the company is going to sponsor the next Conference in Seattle, US, in 1986, which will concentrate on the industrial application and utilization of chitosan.

The industrial application of chitosan and its derivatives can be very wide. Present application on a commercial scale is in waste water treatment, as a protein coagulant. Use of the commercially available chitosan for potable water purification has been approved by the US Environmental Protection Agency. Chitosan can also be used for the removal of heavy metals and trace elements, including plutonium and uranium. Promising results have been also obtained using chitosan as an hemostatic agent (Fradet, 1985). Chitin and its derivatives are biodegradable and degradation products do not introduce any disturbances to human bodies. This makes chitin an appealing substance for the controlled release of drugs, nutrients, agriculturals, chemicals, etc. (Muzzarelli, 1977).

There are three main limitations for the food application of chitosan's polymers: first, the properties of chitin/chitosan vary with source and method of preparation; second, chitin has not yet been petitioned to the US Food and Drug Administration for food use, although an approval for chitosan as a feed additive has been granted recently; and third, there is very little information on chitin/chitosan metabolism in humans (Knorr, 1984). However, increased demand for chitin/chitosan application would be an important step towards overcoming these limitations.

Present production of chitin/chitosan is concentrated mainly in Japan and the US,and the latest problem to solve is the standardization of high quality products.

Prices for the final product vary from US$ 4 to 25 per kg, depending on the quality, the type of derivatives and the quantity ordered.

4.7 Other by-products

Enzymes

Research on the digestive tract of krill have shown the presence of numerous enzymes which could find practical application in several industries -- food, animal feed, tanning, pharmaceuticals, etc. However, this would entail the transport of large amounts of fluid containing small amounts of enzymes. At this time, there is no information on the practical utilization of krill enzymes besides laboratory research.

Krill oil

Despite intensive testing and the use of additional operations (Schreiber et al.,1979) it was not possible to obtain krill oil by centrifuging in traditional equipment. This is connected to the properties of krill lipids.

Krill oil was only obtained by extraction with the help of various organic solvents. Because of its high content of phospholipids and fatty acids, krill oil could be a valuable raw material for oil, cosmetic and pharmaceutical industries. However, since extraction costs are high and special installations are needed, it is unrealistic to expect production of krill oil in practice.

4.8 Health aspects of krill products

4.8.1 Food products

After the required tests, many krill products are available on the USSR market. These include canned krill meat products and canned products containing "Ocean" krill paste. A similar situation exists in Japan. In 1982, one Japanese firm made an offer to sell krill meat in the US and Canada.

Polish health authorities have treated krill products as a novel food. Extensive, long-term toxicological tests of roller-peeled krill meat were carried out. These tests conformed with the WHO standards. In October 1984, the State Institute of Hygiene in Warsaw stated that peeled krill is non-toxic. According to Polish regulations, such opinion entitled the Sea Fisheries Institute to apply to the Minister of Health for admittance of krill meat as food. In 1984, an American firm tested Polish roller-peeled krill meat as an additive to food products. In 1984, the Medical Academy in Poznań finished preliminary toxicological investigations of krill precipitate, approving of the product. It should be noted that tests of Polish coagulated paste were abandoned in 1979 because of negative results.

In 1981, the US Food and Drug Administration stated that the tail meat of krill, excluding the exoskeleton, is a food, reversing its earlier position which held that krill was a food additive. Americans have concluded that the 14 ppm of fluoride contained in krill meat do not constitute a health hazard to man (Anon., 1981).

Several products are close to this level:roller-peeled meat, krill precipitate and mince in the modified version (Bykowski and Dutkiewicz, 1984; Christians, Leinemann and Manthey, 1981; Kolakowski, 1982). It may be expected that the level of fluoride in the meat obtained by the Soviet method of crashing and flotation is equally low. Polish research in this field, interrupted in 1979, resulted in a product containing 35 ppm of fluoride (Bykowski, Kostuch and Kowakzuk, 1981).

It is obvious that attempts should be made to lower shell, and thus fluoride, content in krill products still further. However, there are technological constraints here, e.g., separating capabilities of centrifuges, difficulties in constructing and cleaning drum separators with holes below 1 mm in diameter.

A solution of the fluoride problem may lie in the use of krill products as food additives. For example, a Danish firm from Bornholm applied to Poland for the sale of coagulated paste. It later used it as an additive to fishburgers, which improved their colour and taste. This product contained negligible amounts of fluoride and was approved by health authorities.

4.8.2 Animal feed

Krill meal and frozen krill are used as animal feed with no restrictions in the USSR, Japan and Chile. At the end of the 1970s, Poland sold several hundred tons of frozen krill and krill products to Norway, where they were used to feed salmonides. Beginning in 1977, Poland conducted extensive research on the use of krill meal as feed. Zootechnical investigations resulted in some negative effects. Negative effects were observed when large doses of krill meal, exceeding those used in breeding practice, were given.

Tests of krill meal utilization assumed a new direction when the meal was found to have a high fluoride content. This substance exceeds four times the allowable amount in feed for the EEC countries (EEC, 1973). This might explain the above-mentioned negative results of some experiments (Minta, Szprengier and Bienacki, 1979; Pastuszewska, Lis and Wyluda, 1979; Siebert et al., 1982).

The method for low-shell krill-meal production, worked out in Poland, has poor prospects because of the high cost of the necessary separators and the low yield. Therefore, further research was undertaken on the possibility of using whole krill for meal production. To define "safe" doses of meal, the animals' tolerance to fluoride, the degree to which it is assimilated, and the amount of this element accumulated in their meat and eggs were determined. The allowable amount of fluoride in pig feed is about 150 ppm, for broilers about 200 ppm. Taking into account the amounts of fluoride introduced with the feed phosphates, the "safe" amount of meal that may be added to mixtures equals 3 per cent for pigs and broilers. Krill meal should not be used to feed animals sensitive to fluoride, e.g., cattle and animals kept for breeding purposes. A certain level of fluoride does not cause an increase in the fluoride level in animal muscles (Pastuszewska, 1984).

Krill meal and frozen krill are an excellent feed for salmonides (Koops et al., 1979; Trzebiatowski, Domagala and Filipiak, 1979; Goryczko and Gliszczyński, 1981). Three-year-long investigations of salmon and trout, fed exclusively with krill, showed that the level of fluoride in their muscle was lower than that in Baltic fish from the same area (Grave, 1981). This author believes that there are no contra-indications to the feeding of salmonides with krill.

4.9 Location of processing facilities

Due to its technological properties, the raw material should be processed as soon as possible after capture. The only way to meet this requirement is to install processing facilities on-board the vessel. Two factors determine such choice. The first is product quality since only fresh krill may be used for good-quality products or semi-products, both for human consumption and animal fodder.

The second factor is the effectiveness of krill fishing. Because of the large distance between the fishing grounds and harbours, in the case of Europe, the weight and volume of the transported product should be reduced to a minimum. Such a tendency may already be observed today, e.g., freezing of krill for animal feed was severely limited on Soviet vessels. The installation of high-yield separators on board will permit the production of meal of a higher quality, devoid of krill shells. It may be expected that more finished products, such as canned meat and small meat portions, will be produced on the vessel in the future. This is connected with technical possibilities on board. At present, factory trawlers, adapted for krill processing, are being used; advanced krill processing is not possible as these vessels usually retain fish-processing equipment used for the remaining part of the year. So far, there is no information on the building of special vessels for krill fishing and processing, although such a vessel has been designed. However, fish-krill vessels are under construction; their design and equipment will allow a more effective utilization of the raw material, mainly for canned products.

It is unrealistic to believe that krill may be processed in old whale-processing plants in South Georgia. The fishing season there is short and the catch rate undergoes considerable fluctuations. Despite short transport (several to over ten hours), the processing would be limited to krill meal, which is unlikely to be profitable.

5. ESTIMATES OF PRODUCTION COSTS, PRICES AND DEMAND

The krill market is not yet developed and the knowledge of technological parameters of fishing and processing operations contains many gaps. Nevertheless, their number gradually decreases as a result of trials, experiments and design work so that preliminary economic estimates of certain feasible variants in the commercial exploitation of krill may be attempted. The present attempt is based on the results of our own research and on data contained in the reference papers on the subject. Priority has been given to the results of Polish investigations and experiments, in particular, the following parameters bearing upon economic evaluation: length of the krill catching season, average daily catch rate per day fished, area of operations, yield in krill peeling and its reduction to feed, characteristics of a factory trawler best suited for krill exploitation, most advantageous method of processing, and other vital elements.

These data have been supplemented with the findings of such authors as Eddie (1977), McElroy (1979), Mitchell and Sandbrook (1980). These sources helped to form a general concept of exploitation which would seem profitable in practice, and to select products that could be expected to meet with a favourable reception on the market.

5.1 Exploitation option

5.1.1 Basic assumptions

The assumptions and calculations presented below do not claim to embody the best and only exploitation model worked out, for instance, by the use of an operational analysis. For the optimization of the exploitation model, not all data are available, e.g., the size of demand and the prices the consumer would be willing to pay for krill products.

The following was used to calculate the costs of a completely new experiment:

a) The economic evaluation is based on the free market system. None of the cost elements include subsidies.

b) The main product made at sea immediately after capture would be roller-peeled tail meat. Krill meal would be produced from that part of daily catches that would not be used for tail meat, either because of the limited processing capacity or the low quality of the raw material.

c) Tail meat would be frozen on factory trawlers in blocks packaged in cardboard boxes and transshipped onto freezer-carriers, which would supply it to a given port of the US, Europe or elsewhere.

d) Tail meat, frozen in blocks, would be treated as a semi-finished product and supplied to selected countries with a traditional shrimp market; there, it would be processed into finished products in demand on the market. It is expected that tail meat may be sold in the form of the following products: cocktails, salads, shrimp paste, breaded sticks, sauces, soups and stews. Restaurants and other institutional buyers would be the main customers.

e) No market exists for krill products. It will be necessary to use promotion, which will require close cooperation between local processors and the fishing company supplying peeled tail meat in frozen blocks.

f) The promotion period may last as long as two to four years, beginning with the date of supply of many consignments, each not smaller than 10 tons. However, already after a year or two, the producer (fishing enterprise) will know whether further investments in krill exploitation will be profitable; he may then decide to build a series of krill peelers and adapt a larger number of vessels for krill harvesting.

g) The present calculation refers to the first phase of promotion, in which, for instance, one or two commercial trawlers may be used. Initially, three krill peelers are to be installed on each vessel, with a total processing capacity of 30 000 kg of whole krill into 4 800 kg of tail meat in 20 hours of work per day. In sea conditions, due to interruptions in krill harvesting or short breakdowns in prototype machines, the practical daily processing capacity will only be 25 000 kg of krill, from which 4 000 kg of tail meat will be obtained.

h) The second phase of this exploitation option will differ only by a larger number of krill peelers installed on each vessel (e.g., six instead of three) and, consequently, increased processing capacity for tail meat, accompanied by a decline in krill meal production. This could be a target stage for the commencement of normal commercial profitable exploitation of krill stocks for a given fishing company. However, this phase may begin only after demand for the product has been created.

i) In the present section, all costs have been calculated in US dollars on the basis of the 1984 fuel prices, materials and services. The calculations are also based on the assumptions that daily catch rate is 55-60 tons of krill throughout all 106 fishing days and that all other factors remain the same.

j) Mean yield in krill peeling by roller-peelers is assumed to be 16 per cent,in processing of whole krill into meal 14 per cent. This is a fairly cautious estimate. It is possible that, in mass production, the yield will be higher as was the case on certain days during various research cruises.

k) The exploitation option assumes that krill will be processed on the vessel immediately after each haul. Other options have also been considered, especially catching krill by medium-sized trawlers and transporting fresh for processing on land or transshiping onto floating processing plants. However, none of these optionsseems feasible because raw krill spoil too rapidly. The use of buffer storage with chilled seawater is good only for small surpluses of raw krill for a short period between hauls. However, it is impossible to keep the raw material from a whole fishing day in good condition, not to mention catches from several days. Preliminary calculations have also shown that the option of freezing raw krill on board and the later processing into finished products on land is of little viability. There could be exceptions to this rule when it becomes possible to sell whole frozen krill at high prices to the end users.

5.1.2 The vessel

Krill-peeling equipment with auxiliary machines for production may be easily installed on six types of currently used Polish fishing and factory trawlers. They can be installed for six months, dismounted in a couple of days in a harbour close to the fishing grounds, and replaced with fish- or squid-processing equipment. For three krill peelers installed, an additional evaporator, capable of producing 10-12 tons of fresh water per day because of the increased consumption of fresh water in krill processing, is also necessary.

It has been decided that in the first stage of the venture, in the 1985/86 fishing season, one B-414 factory trawler will be used. Its characteristics are as follows:

Length overall	about	90.00 m
Length between perpendiculars		81.60 m
Breadth, mld		15.00 m
Design draught		5.40 m
Corresponding deadweight		1 500 t
Gross register tonnage		2 600 RT
Speed at 5.20 m draught		15.5 knots
Bollard pull		42 t
Cruising range in nautical miles		16 000
Endurance in days		80
Main engine at 500 rpm		3 600 BHP
Electric energy supplied by two alternators with output		780 kVA
plus two alternators with output		700/850 kVA

Hold capacity for:	
frozen products (-28°C)	1 430 m^3
fish or krill meal	470 m^3
fish oil	60 m^3
Refrigerating capacity per day	45 t
Fish-processing equipment consists of 33, 181, 189, 188, 694 Baader machines and others which would be replaced for six months by krill peelers with associated devices.	
Raw material throughput of fish-meal plant	50 t

B-414 type vessels were built in the years 1975-1977. The ones that will take part in experimental krill-fishing operations in 1985 to 1988 will thus be 10 years old on average. Older vessels built in 1967-1972 might also be used so as to reduce the cost of the experment.

5.1.3 Catching cycles

Long-term practice in fish harvesting on the main fishing grounds of the Atlantic and Pacific, as well as the known location and seasonality of krill, suggest an exploitation model with the following characteristics:

a) As has been standard practice in fishing in Poland for the past few years, the trawler leaves the port of registry for several years (e.g., four) and returns only for a periodic overhauling. The base port for supplying the vessel with fuel and food, and for possible repairs, is chosen close to the fishing ground. When the hold has been filled, the products are transshipped onto a freezer carrier, which also supplies the vessel with fuel and other necessary materials for the cruise. The ratio of fishing trawlers to freezer carriers and mother ships depends on the size of the latter and the distance between fishing grounds and base ports. The use of Polish auxiliary vessels to aid trawlers fishing for krill presents no difficulty. Polish trawlers fishing for fish and squid have been operating for several years now close to krill fishing grounds in the vicinity of the Falkland Islands. Shuttle-like use of Polish auxiliary vessels has, therefore, been maintained to service this fleet. With no considerable cost increase, they may service several krill trawlers. In this way, Polish vessels fishing for krill would be automatically incorporated into the fish- and squid-harvesting system in the vicinity of the Southern Ocean.

b) The crew of the trawler is changed every few months; it is brought by air from the mother port (Gdynia) to the base port in South America and the other way round.

c) The B-414 vessel fishing for krill will be involved in fishing operations for a period of five to six months (e.g., from December until May). In June, krill peelers will be replaced by fish-processing equipment in the base port in South America. The vessel will conduct traditional operations for fish and squid for the remaining five to six months of the year.

d) Fishing operations after the krill season will pose no problem since the captains are well acquainted with fish- and squid-fishing grounds located close to krill-fishing areas. Possible daily catch rates are also well known. The squid fishing season overlaps to a large degree with the krill season. It is known that for two months after the krill season, the vessel will catch squid and fish for the remaining four months. It is also known that the value of fish and squid caught will more or less cover the costs of the vessel exploitation in the six months outside the krill season. The production schedule for a factory trawler fishing year-round for krill, fish and squid is shown in Table 14.

5.1.4 Expected output of fishing operations

The results of krill catches and processing given in Table 14 require additional comment. They refer only to the first phase of the experiment, when the trawler will be equipped only with three peelers and associated auxiliary equipment.

Table 14

Annual time sheet and output of a vessel in the krill, fish and squid-catching option

Character of activities	Days		
	catching krill	catching fish and squid	overall fishing
Number of calendar days	182	183	365
minus overhauls and repairs	28	12	40
Disposal time for operations	154	171	325
Lay days in base harbour	6	6	12
Time at sea	148	165	313
Lay days at the subsidiary and transport vessel for discharging of cargoe and taking supplies	15	15	30
Position trips (searching for schools and voyages to harbour or transport vessel)	22	30	52
Other unproductive days	5	10	15
Total fishing days	106	110	216
	tons		
Average daily catch rate	55	41	
Catch in live weight	5 830	4 510	10 340
Output:			
krill tail meat	424		424
fish fillets		810	810
fish gutted and headless and processed squid		935	935
Meal	445	495	940
Products weight	869	2 240	3 109

A question may arise as to why only three units of this kind are installed, since their daily throughput amounts to 25 tons of raw material while the vessel is to catch 55 tons on the average, and the surface area of the vessel allows for the installation of as many as six machines. There are two reasons for this.

Firstly, the enterprise engaging in experimental krill catches does not intend to invest large amounts of money in mass production of krill tail meat until demand and prices have been determined.

Second, taking into account the large fluctuations of individual hauls, ensuing from the eccentric and unstable character of krill swarms, various technological value of krill specimens, and changeable weather conditions, the percentage of catches that can be processed daily throughout the whole season into tail meat has not yet been fully determined.

Table 15 presents expected production in the krill season during the first phase of the experiment.

Table 15

Expected input-output ratios per vessel duri the krill season in Phase I (3 krill peelers

Raw material used	Per fishing day			Per season		
	raw material (in tons)	yield (in %)	product (in tons)	no of fishing days	raw material (in tons)	product (in tons)
For tail meat	25	16	4.0	106	2 650	424
For meal	30	14	4.2	106	3 180	445.2
Total	55		8.2	106	5 830	869.2

The above expected results are believed to be highly realistic as the main value for input-output, i.e., daily catch rate, was based on the results attained in earlier cruises of Polish vessels. The yield obtainable in the course of processing in tail meat and fodder meal has likewise been confirmed by earlier practice. The Table does not include the option of freezing whole raw krill on certain days of peak catches, which may take place if such product is in demand and there is enough space in the hold left after storing peeled tail meat.

Table 16 presents the expected production during the second phase of the experiment. Mean daily catch rate was increased to 65 tons, and the number of krill peelers to six, their total daily processing capacity amounting to 50 tons of raw material, i.e., 8 tons of pure tail meat.

Table 16

Expected input-output ratios per vessel during the krill season in Phase II (6 krill peelers)

Raw material used	Per fishing day			Per season		
	raw material (in tons)	yield (in %)	product (in tons)	no of fishing days	raw material (in tons)	product (in tons)
For tail meat	50	16	8.0	106	5 300	848
For meal	15	14	2.1	106	1 590	226.6
Total	65		10.1	106	6 890	1 070.6

The data presented in this Table are less reliable than those presented in Table 15; the daily average catch rate of 65 tons may turn out to be overestimated. The assumption that out of 65 tons per day about 77 per cent (50 tons) of the whole catch could be processed into pure peeled tail meat also seems excessively optimistic. On the other hand, such optimistic prospects cannot be excluded as daily catch rates on many days of previous cruises were considerably higher than 65 tons and the whole bulk of krill was of good quality and could have been used for peeling. At that time, however, the number of well-designed krill peelers on board was insufficient for rational utilization of such good krill catches. Hence, the results of the first stage of the experiment will eventually clarify which data are realistic and which are not and allow for adjustments of the figures given in Tables 15 and 16.

In turn, Table 17 presents the expected amounts of krill meal obtainable on a B-414 or similar factory trawler if no equipment for krill processing into food products is installed on them. Two variants are given: for a daily catch rate of 55 and 65 tons.

Table 17

Input-output ratios per vessel during the krill season presenting two alternatives and assuming the entire catch is reduced to meal

Phase	Per fishing day			Per season		
	raw material (in tons)	yield (in %)	product (in tons)	no of fishing days	raw material (in tons)	product (in tons)
I	55	14	7.7	106	5 830	816.2
II	65	14	9.1	106	6 890	964.6

It appears that from 816 to 964 tons of krill meal could be produced during the whole season. A comparison of the economic viability of utilizing krill for meal and food products is presented in the following section.

5.2 Production costs

5.2.1 Cost specification per vessel

As mentioned above, the vessel will catch krill, fish and squid all year-round and will be part of the exploitation system of Polish fishing and support vessels already operating in FAO Major Fishing Areas No. 41 and No. 48.

That is why full costs of vessel operation connected with both fish and krill catching are presented here. The estimate of individual cost elements was based on results attained in the past few years. It should be mentioned, however, that overall costs of the vessel in Phase II will be higher than in Phase I.

Table 18 presents the expected operating costs and overheads of one vessel during both phases of the experiment.

A large part of the cost elements are assumed to be the same during both phases of the experiment, in particular fuel costs, wear of nets and other materials, crew subsistence allowance, and some other expenses.

The emphasis in the experimental stage of fishing will be placed on long uninterrupted operation of new prototype krill peelers. They should work not less than 100 days at maximum number of hours per day, and with the maximum possible amounts of krill processed into tail meat. The reason for this is the need to determine for future use the number of peelers necessary and the general daily peeling capacity for peak and average daily catch rates.

Table 18

Annual operating costs for a B-414 vessel
(in US$ at 1984 prices)

Item	Phase I (3 krill peelers)	Phase II (6 krill peelers)
Fuel and oil consumption	490,000	500,000
Fishing gear	176 000	176 000
Packing materials	25 000	50 000
Other direct materials	140 000	140 000
Crew remuneration	459 000	636 000
Subsistence allowance for crew	156 000	156 000
Repairs and overhaul	286 000	286 000
Insurance fees	90 000	140 000
Harbour fees	112 000	112 000
Services of freezer carrier (transporting finished products and providing supplies)	287 000	497 000
Other direct costs, including air fare of the crew	337 000	337 000
Direct operating costs (sub-total)	2 558 000	3 030 000
Vessel depreciation	390 000	420 000
Departmental overheads	190 000	190 000
General and administrative costs	189 000	189 000
Selling costs	24 000	24 000
Interest and contingencies	162 000	186 000
TOTAL	3 513 000	4 039 000

In the second phase of the experiment, certain costs will rise, e.g.: remuneration of the crew which, besides fixed salaries, receives a percentage commission on the value of the catch; services of auxiliary vessels, in particular, the transportation of peeled tail meat to different harbours by freezer carriers; packaging materials due to increased quantities of finished products; depreciations associated with additional krill peelers put on the trawler; interest and contingencies.

Selling costs are very low and constant for both phases because it is assumed that all promotion costs for the new product will be borne by the customer on land. With regard to freight expenses and other costs connected with the supply of krill tail meat in frozen blocks to various ports, these are included under the item "Services". These are quite high and constitute 11.2 per cent of direct operating costs in Phase I and 16.4 per cent in Phase II.

5.2.2 Unit costs of krill catching and processing

To obtain unit cost of krill products, it is necessary to isolate the krill cycle from the traditional fish- and squid-catching cycle within total annual costs. These are two different spheres of activity. The products obtained during the traditional cycle are sent via auxiliary vessels to the domestic market in Poland. The period devoted to krill

harvesting is a time for experimenting, during which problems of marketing and production viability should be solved.

The division of total annual costs into krill and traditional cycles will be made on the basis of the time spent for each by the vessel. The criterion may be either days at sea or fishing days. The value of each of these criteria is given below in US dollars:

	Phase I	Phase II
Cost of one day at sea	11 223.6	12 904.1
Cost of one fishing day	15 753.4	18 112.1

The criterion of days at sea seems to be a better one. The expression "day at sea" is closely associated with the goal of the vessel's operation and the means expended on it. Thus, total cost of each of these cycles for one B-414 factory trawler will be the following:

	Phase I	Phase II
Fish- and squid-catching cost	1 851 894	2 129 176
Krill-catching cost	1 661 093	1 909 177
Total per annum	3 512 987	4 038 983

Unit cost of roller-peeled tail meat in frozen blocks will thus assume the following values:

	Phase I	Phase II
Total cost of krill catches per vessel	1 661 093	1 909 177
Minus value of krill meal (about US$ 350 per ton)	155 820	77 910
Cost of obtaining tail meat (424 tons in Phase I and 848 tons in Phase II)	1 505 273	1 831 267
Cost of 1 ton of tail meat	3 550	2 159

Rounding off these figures, the cost of manufacturing 1 kg of krill tail meat delivered in frozen blocks and treated as a semi-finished product by inland processors would most likely amount to US$ 3.60. It may be expected to drop to US$ 2.20.

Expected estimated costs of meal production when all raw material taken is processed into it are presented below. As far back as 1977-1979, it was found on the basis of Polish experimental catches that the production cost of krill meal is relatively high. Counting unit cost at factor prices of 1979, it was the following:

for standard krill meal - about US$ 1 470 per ton

for low-shell krill meal - about US$ 1 960 per ton.

Calculating these costs for the expected daily catch rates of 55 and 65 tons, at factor prices of 1984, figures for krill meal will be the following:

with a daily catch rate of 55 tons and 5 830 tons of raw material per vessel during the whole season, i.e., 816.2 tons of krill meal and the total cost of US$ 1 661 093, the cost of one ton of krill meal would be US$ 2 035;

with a daily catch rate of 65 tons and 6 890 tons of raw material processed into 964.6 tons of krill meal, with the total cost of US$ 1 909 177, the unit cost would be US$ 1 979.

These unit costs considerably exceed fish meal prices on the world market.

As can be seen from these figures, unit cost for krill meal is only slightly lower than the unit cost for krill food products. This is because the yield obtained during reduction to meal is almost equal to that obtained during krill peeling for food products.

5.3 Marketing of krill products

5.3.1 State of marketing research

There is a large disparity between the involvement of various fishing companies in research on the extraction and processing of krill and the activities of marketing companies aimed at selling it. This disparity is especially apparent if measured in funds already spent on krill development. While the former have already allocated millions of dollars for basic and applied research, the latter do not seem to have ventured much. Hence, extensive, systematic and impartial processing and marketing research still has to be carried out.

What is desired in the present state of krill development is marketing research on behalf of the manufacturers, i.e., fishing companies that are taking the risk of losing enormous funds. Research should cover the following aspects of selling possibilities: real prospects for the new product; handling of semi-finished products (frozen blocks); manner of processing into finished products; range and forms of finished products; packaging and labelling designs; attitudes and responses of consumers to product tests; location of consumer centres; scope and costs of required promotion and advertising, if any; finding and selecting the best distribution channels; prices attainable for those commodities.

It is assumed that marketing research does not have to start from scratch, i.e., from concept tests. The concept of manufacturing peeled krill tail meat appears to be sound. Samples have recently been distributed among US importers and processors. Marketing companies willing to be involved in krill trading and processing should start with the tests of various finished products combined with commercial tests on a relatively large scale.

A very important issue must be clarified as soon as possible in the course of this research. Should peeled krill tail meat be treated as an entirely new product or a substitute for shrimp, or perhaps be ranked as a very small grade of shrimp, according to marketing criteria? Biologically, krill obviously do not belong to the same species as shrimp but commercially they could pass for very small shrimp because of their taste, flavour and nutritive value. This question appears to be the most crucial for the viability of commercial exploitation of krill for direct human consumption.

5.3.2 Pricing assumptions

At the present stage of research on krill utilization, prices and demand remain the most difficult problem. Unlike technological solutions, these cannot be anticipated with any degree of certainty on the basis of activities on a laboratory or semi-technological scale. Price levels must be determined by supply and demand based on mass production. However, krill products have not yet entered the world market. There are no representative numbers of international transactions to determine prices. It is not yet known which food products manufactured so far would be in demand on the market at a price that would bring profit to the producer.

The USSR and Japan, the two largest exploiters of krill resources, have directed krill products towards their domestic markets, and the whole range and size of production was experimental until 1984. The scale of experiments on catch quantity, product variety, the funds allocated, and especially the continuity of research have been much lower in other countries.

In our opinion, it would be fallacious to claim that a price of US$ 1 050 per ton of whole krill frozen in blocks is attainable worldwide. This is a highly exceptional price, acceptable only to a specific group of customers in Japan and covering negligible supplies.

As far as mince and meal are concerned, the issue is paradoxically both simple and complex. Its simplicity lies in the method of anticipating prices as it may be expected that the price of minced krill will be determined by the prices of such competitive products as minced fish made from suitable species. The price of krill meal will also be determined exclusively by similar quality standards of fish meal. This was the basis for the assumption of a price of about US$ 350 per ton of krill meal, containing proper amounts of protein and fat, in the previous section.

The difficulty lies in the necessity to supply these products at prices competitive with those of the original products. As far as krill meal is concerned, the Polish experience has shown it to be impossible. The production of krill meal on factory trawlers is much more costly than the production of fish meal in land-based plants from trash fish taken close to land or fish offal from fishing vessels.

Our experience does not allow us to predict whether anyone will manage to start mass production of minced krill at competitive prices before the end of the 1980s. We also do not know whether krill paste made from coagulates will be widely accepted on the market at a price covering production costs. It has been our experience that there are many constraints here of an economic character.

The production of tail meat raises certain hopes, as mentioned above, in terms of economic factors. Due to the absence of comprehensive and conclusive market research within the option presented in the preceding section, we have had to rely upon suppositions or even guesses to forecast a price.

These suppositions result from partial indirect investigations, and in particular from the review of papers dealing with krill development, published until 1984, and personal communication and correspondence with certain shrimp importers and processors in the US who have been provided with samples of peeled tail meat in frozen blocks. The US shrimp processors assert that they would be in a position to handle krill tail meat and sell it in various forms as analogues of shrimp products, though at slightly lower prices than the lowest grade headless frozen shrimp.

This opinion coincides to a great extent with that of Grantham (1977), who was probably the first researcher to think that krill tail meat could be treated as shrimp. However, he thought it unlikely that the price of krill tail meat could be higher than 70 per cent of the locally prevailing price for small shrimp. Eddie (1977) assumed that the price for krill tail meat obtained by attrition or roller-peeled would be of the order of US$ 2 000 per ton, which was close to that of the lowest grade shrimp in 1976.

Average prices of lowest grade frozen headless shrimp shipped in 1984 from India, Pakistan and Sri Lanka were quoted by INFOFISH Trade News as follows:

US ports, from US$ 3.75 to 4.00 per kg;

Japanese ports, from US$ 3.30 to 3.80 per kg.

India, Pakistan and Sri Lanka were considered cheap suppliers. Some best-quality low-grade (count 71/90) headless shrimp coming from other countries were sold on the US market at prices ranging from US$ 4.00 to 5.20 per kg.

Hence, applying both Grantham's index of 70 per cent and the opinion of the US shrimp processors, we could envisage that C.I.F. price of tail meat would range from US$ 2.50 to 2.90 per kg.

A slightly more optimistic view of some experts would put the wholesale market price of tail meat on the US and Japanese markets at between US$ 3.00 and 4.00 per kg.

On the other hand, we cannot ignore the opinion expressed by Mitchell and Sandbrook (1980) that the value of tail meat would be largely determined by its "least value usage"; in this case, the wholesale price may range considerably, from US$ 1.00 to 4.00 per kg.

The "least value usage" is assumed to be the final destination of semi-finished products from frozen tail meat which could be converted into cocktails, salads, breaded sticks, stews and other retail products or restaurant dishes. It is supposed that tail meat could be used in both options as an additive and individual product.

A specific approach to the pricing problem has been used by some experts and managers of a Polish enterprise. After research, they concluded that tail meat must be marketed at a price equal or higher than that of quality fish products exported by the company. The following average prices may be quoted as a measure of quality fish products delivered in 1984 to US or EEC markets:

cod fillets, layer-pack:	US$ 2.20 per kg
cod fillets, IQF-pack:	US$ 2.50 per kg
sole fillets, block-pack:	US$ 2.45 per kg
sole fillets, IQF-pack:	US$ 3.52 per kg
halibut fillets, layer-pack:	US$ 2.50 per kg.

Taking into account all approaches and known facts, a C.I.F. price of tail meat in frozen blocks ranging from US$ 2.50 to 2.90 per kg during Phases I and II of the experimental fishing can be achieved.

Still, it must be admitted that the whole problem of pricing tail meat remains hazy. Many more samples and bigger cargoes of frozen tail meat must be delivered continously for a period of a year or two to selected prospective markets so that price predictions can be reliable for project evaluation. A Polish enterprise is willing to sell the product during the first phase of experimental fishing at an average price of US$ 2 500 per ton. This would entail losses of US$ 1 050 per ton. The enterprise is ready to suffer these losses for a year or two as it is confident that it could regain them with surplus after the market has accepted the new product.

There is a different problem with a product that has been produced in the Soviet Union on an experimental scale for several years. Its organoleptic properties are very good and its resemblance to shrimp in this respect is great. It is possible that promotion of this product on the shrimp market would be easier and faster than for krill tail meat in frozen blocks. However, the retail price on the domestic market of the USSR is very high, as the product is not only peeled but also canned at sea. It is not known whether the price attainable on the world shrimp market would cover production costs.

5.3.3 Problems in estimating supply and demand

As might be seen from the preceding sections, this study concentrates on a high-quality and low-volume product. This approach to krill utilization, at least in the initial stage, results from the following line of reasoning.

First, krill catching and processing is a capital-intensive venture. The tremendous initial outlays to start catching operations cannot be repaid by a cheap product.

Second, low-volume production cannot have a serious impact upon the state of resources; this approach is necessary until the total allowable catch can be unmistakably assessed and apportioned to the countries applying for catch quotas.

Third, the low-volume and high-quality products venture appears to be the only viable one at present in the opinion of the would-be manufacturer, i.e., Dalmor.

Food products

It appears from offers received by the Polish enterprise that several thousand tons of tail meat could be supplied to the North American market already in 1985. Some contractors in the US have worked out various forms of final products for retail and institutional buyers. On this basis, it is believed that the US market would be the best, both as regards the size of demand and the speed with which retail final products and restaurant

dishes could be introduced. It is thus expected that the promotion period would be short in the US market (one or two years), which is of course in the interest of the producer. If the first phase of the experiment proves successful, the enterprise would like to proceed to the second stage without excessive financial risk, knowing already the price and actual demand for the new semi-finished product supplied to inland processors.

According to reference papers, some Japanese fishing companies have also explored the possibility of supplying roller-peeled tail meat to the US market since 1982. There are no details concerning the results of these ventures so it is impossible to determine whether the Japanese price and demand assessments are similar to the Polish ones. So far, only a handful of rough estimates from previous years has been published. Thus, Mitchell and Sandbrook assumed that krill tail meat could gain a position of, say, 10 per cent in the edible shrimp market, i.e., about 60 000 tons a year. They also stated: "Further processing into structural unit portion of larger dimension and convenience offer significant promise as a larger volume market." McWhinnie and Denys (1978) estimated the demand on the Japanese market alone at 20 000-30 000 tons per year to be used in kamaboko.

Besides such general estimates, there has not been any reliable scientific projection of demand, either for tail meat or for minced krill and other products for human consumption. Such estimates may only be arrived at on the basis of steady supplies to certain markets.

It seems that the Polish venture, in which the product manufactured by an enterprise from one country is intended for sale on the markets of other countries, is the best way to determine demand. It makes the whole problem more international and enables free market forces to come into play. It is probably a better way than solving all problems of production, supply and economics of fishing operations within one country. Often, the size of demand for a given product and its price in one country do not correspond to those in another country or on another continent (e.g., whole frozen krill).

That is the reason why the enterprise intends to extend its contacts so that, besides US shrimp processors, it will cover EEC countries and, possibly, Japan. When promoting new products, it is advisable to select more than one target market. It is assumed that krill tail meat may fill the gap in supply of certain cold-water shrimp, which has appeared in recent years as a result of a decline in the stocks of Pandalus species in the North Atlantic. The fact that the demand on some shrimp markets is extremely sensitive to price changes should also be taken into account. A rise in the domestic price of shrimp in general is likely to result in increased demand for cheaper small shrimp and the use of competitive substitutes for shrimp.

Thus, in the years 1985-1990, a number of situations may arise in which some shrimp consumers will feel a need to buy cheaper krill tail meat instead of the more expensive shrimp. This may cause sudden demand for krill products provided these are easily available on the market. Someone has to assume responsibility for the difficult task introducing krill tail meat to the consumer. The Polish enterprise intends to take part in those promotional operations as the supplier of first consignments at its own risk. Nevertheless, partners are needed on shrimp markets in at least several countries.

As with demand, it is still difficult to give exact figures for the potential supply of krill tail meat and other food products. If a price ranging from US$ 2.50 to 3.00 per kg of tail meat in blocks could be obtained in unloading ports in the US, Europe or Japan, the enterprise could build a proper number of krill peelers and adjust other vessels for krill catching and processing. In this way, an annual production of krill tail meat of about 5 000 tons could be reached by one enterprise, which would be the beginning of regular, profitable exploitation. It is possible that other Polish fishing enterprises would join in.

It is not known, however, how many fishing enterprises from other countries would be interested in the production of tail meat at a retail price of US$ 2 500 per ton and what fishing potential they would be willing to use for this purpose. The profitability threshold for commencing fishing operations could be higher than US$ 2 500 per ton.

In the exploitation model presented in the previous section, the factory trawler catches fish and squid in the remaining six months after the krill season. The value of the fish and squid caught covers costs of six months' operations of the vessel. The year-round operation of the factory trawler is based in part on the close base port, and mainly on services rendered close to the fishing grounds by auxiliary vessels. That is why the number of fishing days in a year is high. However, a different fishing company may not have such favourable conditions. When fishing operations start in faraway ports of Europe, the US or Japan, the number of days at sea will increase while the number of fishing days and output will drop, making unit cost of tail meat much higher than that calculated for this option. This may discourage certain fishing enterprises from krill stock exploitation, as a result of which the supply of food products will remain at a low level for a number of years.

Animal feed

The problem of demand for krill meal is a separate one. Raw material resources for the production of fish meal are limited. Hence, there is no reason to expect that annual production of fish meal until 1990 will exceed 4.6 million tons whereas potential demand may grow, particularly in some developing countries. This would seemingly create good prospects for the introduction onto the world market of considerable quantities (e.g., one million tons) of a substitute in the form of krill meal. The resources are vast and the technique for the reduction of krill into meal has been mastered. Why, then, should we not exploit such an attractive opportunity?

However, not even 1 per cent of krill meal has been added to the world trade in the first four years of the 1980s. Beginning with 1977, the prices of fish meal dropped below US$ 400 per ton, and stocks increased considerably. The Fishmeal Exporters' Organization (FEO) considered the years 1981-1984 a period of stagnation on a worldwide scale.

The details of this situation are given in annual reports of this organization as well as in the study ADB/FAO - INFOFISH: The World Market for Fishmeal and the Asian/Pacific Region, March 1983. According to these reports, until 1990, the only product competitive with fish meal might be soybean. World production is expected to rise from 82.2 million tons in 1980 to about 125 million tons in 1990, with a mean growth rate of 4.3 per cent in 1985-1990.

Thus, it cannot be expected that the production of krill meal will have a significant share in the world production of fish meal (e.g., 5 per cent) during 1985-1990. It is also doubtful that krill meal will play any major role in world fish meal trading until the year 2000 (see section 5.3.2). However, krill meal will be produced as a by-product in the manufacturing of food products. The quantities of meal obtained in this way will be used by the countries conducting krill-catching operations and will not play any major role on the world market.

6. CONCLUSIONS

The worldwide interest in krill resources observed during the years 1980 to 1984 was much lower than that prevailing during the 1975-1979 period, when many studies published by international, governmental or private institutions had stated that the exploitation of these resources would reduce the deficit of animal protein and even make the problem of under-nutrition in some countries less severe.

During the 1980s, the expected gradual rise in krill catches did not occur, which may be due to the fact that krill products did not turn out to be economically viable. However, research on krill utilization became more selective, concentrating on food products and systems to determine profitable processing options. The results of these investigations may constitute the basis for possible options and an estimate of the size of commercial krill exploitation, for instance, up to 1995.

The difficulties still encountered in the utilization of Antarctic krill for food, feed and other products are greater than those found with other animal raw materials of marine origin. An additional, hitherto unnoticed technological problem with krill processing into food products, and in part also feed, has been the high fluoride contents in the raw material and some products made from it.

Nevertheless, research carried out for many years in various countries has reached a stage when it is possible to start and develop shipboard processing of krill into the following food products: tail meat, canned and minced products.

It is now believed that technologies developed in Japan, Poland and the USSR for the production of krill tail meat, especially by roller-peeling and attrition/flotation, may become the framework for profitable exploitation of krill resources.

To develop commercial fishing operations for krill tail meat production, two main conditions from the exploitation model for trawlers presented in this study have to come true.

First, krill tail meat would have to be accepted on the market as an analogue or substitute for small shrimp. Second, the parameters of the exploitation options, worked out in Poland, have to be fulfilled, i.e., the cost of krill-fishing operations and processing cannot exceed the market price of small shrimp. It is expected that the results of Polish experimental krill catches, as well as those conducted by Japan and the USSR with the objective of intensifying tail meat production, will determine within the next two to three years the degree of feasibility of assumptions concerning supply markets, prices and demand for these products.

It does not seem justified to start mass-scale exploitation of krill solely for the production of krill meal or feed from whole krill.

It should be expected that future krill catches will be used mainly for the production of high-quality, low-volume products for human consumption. The supplies of frozen fresh and boiled krill to regional markets in some Far East countries will be an exception to this rule. There are serious economic constraints to the development of mass production aimed at an increase in supply of highly processed protein products for the developing countries.

The exploitation option outlined here requires a relatively small volume of catches and should not cause any disturbances in the ecosystem of the Antarctic, a specially important consideration in light of the still controversial question of krill biomass estimate and the size of total allowable catch.

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